CLIMATIC CHANGES AND ITS INFLUENCE ON THE RUNOFF DATA OVER A MAJOR RIVER BASIN IN INDIA – A CASE STUDY

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By

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CERTIFICATE

This is to certify that the thesis entitled, "**CLIMATIC CHANGES AND ITS INFLUENCE ON THE RUNOFF DATA OVER A MAJOR RIVER BASIN IN INDIA – A CASE STUDY**", submitted by **Gopal Kumar Sau** in partial fulfilment of the requirements for the award of Bachelor of Technology Degree in Civil Engineering at the National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

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ABSTRACT

Climate change has profound effect on various environmental variables including rainfall-runoff processes in many regions around the world. The changes in rainfall-runoff characteristics directly impact hydrology, water resources management, agricultural practices and the ecosystems. Therefore, it is vital important to investigate the spatial and temporal runoff characteristics to facilitate better water management practices and strategy. In this study, nonparametric statistical methods, namely Mann-Kendall Rank Correlation (MK) method is employed to test the existence of trends in average annual and monthly maximum, and minimum runoff data in the Tel river basin of Mahanadi river basin in Orissa, India. There is an increase in the non-monsoon runoff in the observed discharge station, signifying the potential of longer drought spell and the importance of better water management practices in the future. Changes in the monthly and annual surface runoff of the Mahanadi river basin in India are analyzed and presented in this paper. The trends in the important climatic elements are evaluated by linear trend analysis. The results indicate that there is a significant uptrend in the non-monsoon means monthly and maximum discharge values in the basin based on data from rain gauges – discharge stations for the period 1971-2008. Results of the trend analysis of the stations are presented and discussed. Increase in greenhouse gases in the atmosphere over India, recent land-use pattern changes and agricultural practices in the region appear to have a bearing on the observed trend.

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1. INTRODUCTION

The Mahanadi river basin, one of the major river basins in India, is located between longitudes 80^o 30' and 87 ^{o} E, and latitudes 19^o 21' and 23^o 35' N. The total basin area is about 141 589 km^2 with mean annual river flow of 66,640 million m^3. The entire flow is only due to rainfall in the region since there is no contribution from either snowfall or snowmelt. The normal annual rainfall of the basin is 1360 mm (16% coefficient of variation, CV) of which about 6%, i.e.1170 mm, occurs during the monsoon season (15 % CV) from June to September.

In recent times, atmospheric General Circulation Model (GCM) experiments have indicated that increased concentrations of CO_2 and other trace gases could cause a global warming of 1.5 ^oC to 4.5 ^oC by the middle of the next century (USNRC 1982, WMO 1988). The water resources administrative sector, which is most sensitive to the climatic variations (Chen & Parry 1987, WMO 1987), could be forced to respond in many regions. Climatic change has been defined by Landsberg (1975) as a shift of climatic conditions to a new equilibrium position with values of climatic elements changing significantly. On the other hand, climatic fluctuation has been defined by Landsberg (1975) as a situation of temporary deflection which can revert to earlier conditions or which can be followed by changes in the opposite direction.

In view of this an attempt has been made in the present study to determine any climatic change and its trends in a major river basin in India. For the present study, a specific region in India, the Mahanadi river basin, was selected for analysis. The reason for selecting this basin is its location with respect to the normal position of the monsoon trough and the mean track of monsoon depressions and storms originating in the Bay of Bengal, enabling a good case study of a river basin representative of the Asian monsoon region.

1.1 LITERATURE REVIEW

AK Gosain, S Rao, and D Basuray in their paper "*Climate change impact assessment on hydrology of Indian river basins*" have quantified the impact of the climate change on the water resources of Indian River systems. The study used a distributed hydrological model named Soil and Water Assessment Tool). The initial analysis has affirmed that the severity of droughts and intensity of floods in various parts of the country may get deteriorated. [1]

P.G Rao in his paper *"Climatic changes and trends over a major river basin in India"* concluded that basin rainfall series based on data from 125 stations for the period 1901-80 did not show any significant trend. None of the ten selected stations in the Mahanadi basin was characterised by a significant increasing or decreasing tendency in either monsoon or annual rainfall. [3]

T Raziei, P D Arasteh and B Saghfian in their paper *"Annual Rainfall Trend in Arid and Semi-arid Regions of Iran*" analysed annual precipitation time series from 1965 to 2000 for climate variability and possible trend using nonparametric Mann-Kendal statistic test. The results showed that there is no evidence of climate change in the study area. Although many stations showed negative trends indicating the decrease in precipitation, this trend was not statistically significant at 95 percent significant level. [8]

1.2. RUNOFF

Runoff of a river is the discharge from the river due to precipitation in the river basin. Runoff (RO) is the total amount of water flowing into a stream, or the sum of *direct runoff* and *base-flow*. Runoff of a river is an important factor for the development of water resources in a planned way. To determine the amount of annual runoff, subtract the amount of annual evapo-transpiration from the annual amount of precipitation.

1.3. TREND

Trend is defined as the pattern of gradual change in a condition, output, or process, or an average or general tendency of a series of data points to move in a certain direction over time, represented by a line or curve on a graph. A trend is a steady increase or decrease of the time series characteristics. Natural or man-made changes like deforestation, urbanization, large scale landslide, large changes in water-shed conditions are responsible for the introduction of trend in the time series. Usually a regression trend line supports a plot to indicate the existing trend in a time series runoff data .Trend Analysis often refers to techniques for extracting an underlying pattern of behaviour in a time series which would otherwise be partly or nearly completely hidden by noise (non-periodic undulations).

2. DATA ANALYSIS

2.1. TREND ANALYSIS

The climate change signs and evidence are not the same over the entire globe. While in certain areas an increase of rainfall or decrease of temperature is expected, other areas will suffer from decreased rainfall or increased temperature. Parametric and non-parametric trend analysis tests give us an approximate idea of the existing pattern of precipitation based on the runoff data for a given period in the corresponding region. Trend analysis enables us to look for factors that alter rainfall and temperature patterns in a particular region.

2.2 ANALYSIS OF TIME SERIES

When a series of observations are arranged with respect to time of their occurrences in a systematic order, the resulting series is called *time series*. This series in hydrology is considered as *time-homogeneous,* when identical events in the series are likely to occur at the same time. Due to a large number of caustic factors affecting the phenomena, a hydrologic time series is never time homogeneous. By stationary we mean, the time series segments drawn from the same population should have the same expected value of statistical parameters for each section. Annual series may be stationary but daily or monthly series are never stationary. Properties like trend, periodicity and persistence make the departure of time series from its true homogeneity. They should be identified quantified and removed as they are deterministic in nature. The residuals are stochastic components due to the property of randomness. A random stochastic component is said to be present when serial correlation coefficients of different lags are zero.

In a developing country like India, generation of data is an essential requirement for any water resources project planning management. An effecting generating technique breaks up the data into its components, analyse the mechanism underlying the formation of each constituent and preserve them, while generating the future sequence of the series. Thus, properties of each constituent must be preserved while combining the constituents to form the future time series. We are assuming here that the pattern or the system that has been indentified will continue. When the constituents of time series are not properly identified or the pattern identified does not continue in future, a wrong generating technique is incorporated. This may lead to erroneous results and must be checked and corrected. In a hydrologic time series the constituents like trend, periodicity, oscillation and jump are deterministic in nature which can be quantified and removed. The residual stochastic component is studied and modelled suitably.

3. STUDY AREA

The Tel River originates in plain and open country in the Koraput district of Orissa, about 32 km to the west of Jorigam. Tel is the second largest river of Orissa and flows just eight kilometres away from the town of Titilagarh. This river is a significant tributary of the Mahanadi River. The convergence of the two rivers offers a remarkable view against a colourful landscape. The river traverses a total length of 296 km to join the Mahanadi River on the right bank, 1.6 km below Sonepur. The total drainage area of the Tel River is about 22,818 km^2.

The Tel is a river in the Nabarangpur, Kalahandi, Balangir, and Sonepur district of Orissa, India. The Tel sub-basin is bound between latitude 18° to 21° and between longitude 83° to 86° approximately. A schematic presentation of the path of the River Tel is given at Fig.2

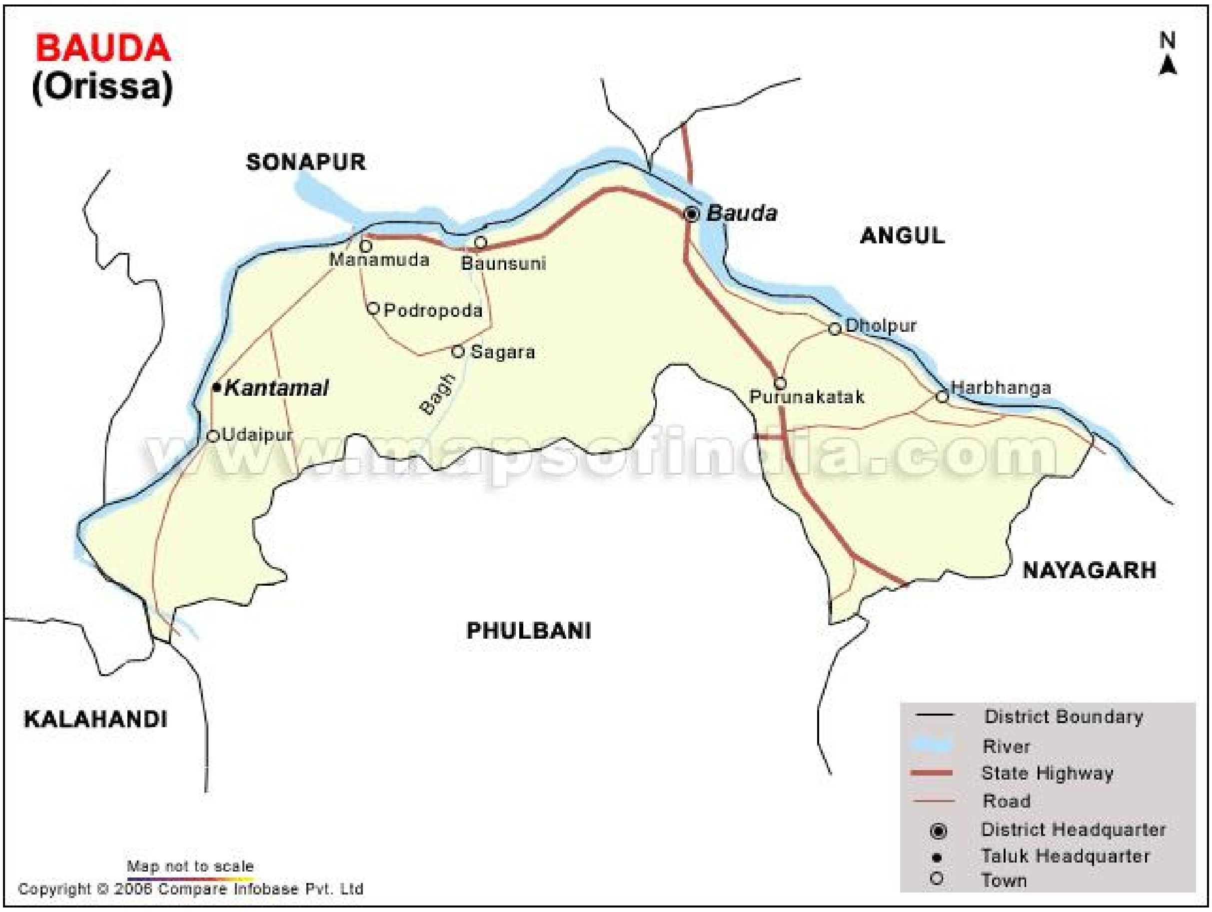


Fig.1. Path of the Tel River

There are approximately 16 rain gauge stations along the Tel sub-basin. According to the convenience of data availability the discharge data of Kantamal and Kesinga rain gauge stations has been taken. Kantamal is in Boudh district and Kesinga in Kalahandi district. Both Kantamal and Kesinga are installed with automatic rain gauge with ID 55C48A82 and 55C42A74 respectively. Kantamal rain gauge station is present in the downstream of Tel river with a catchment area of 19,600 sq. km. Kesinga rain gauge station is present in the upstream of Tel river with a catchment area of 11960 sq.km. The map in Fig.2 shows the schematic relative positions of the rain gauge recording stations.

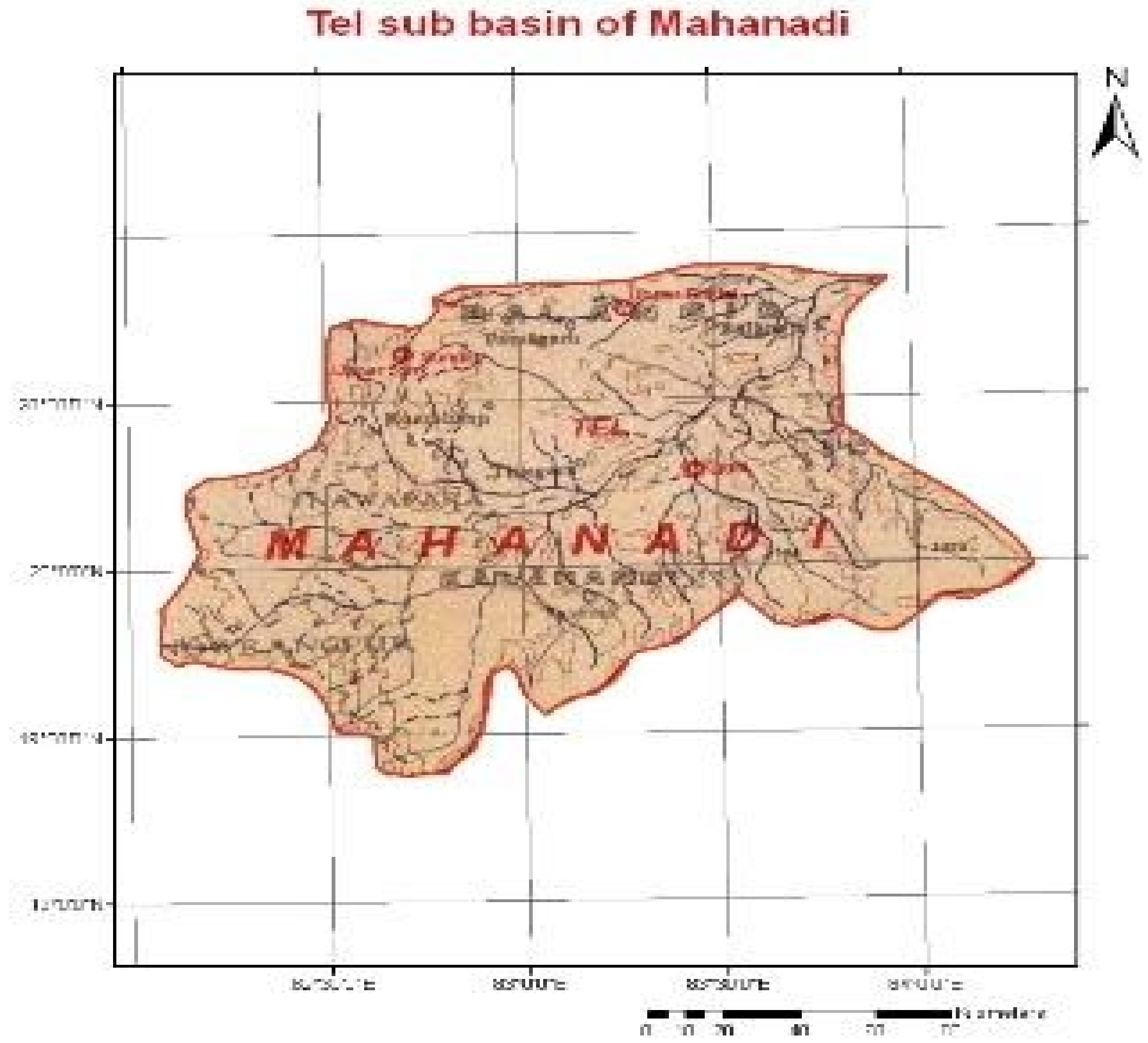


Fig. 2. Tel sub-basin of the Mahanadi basin

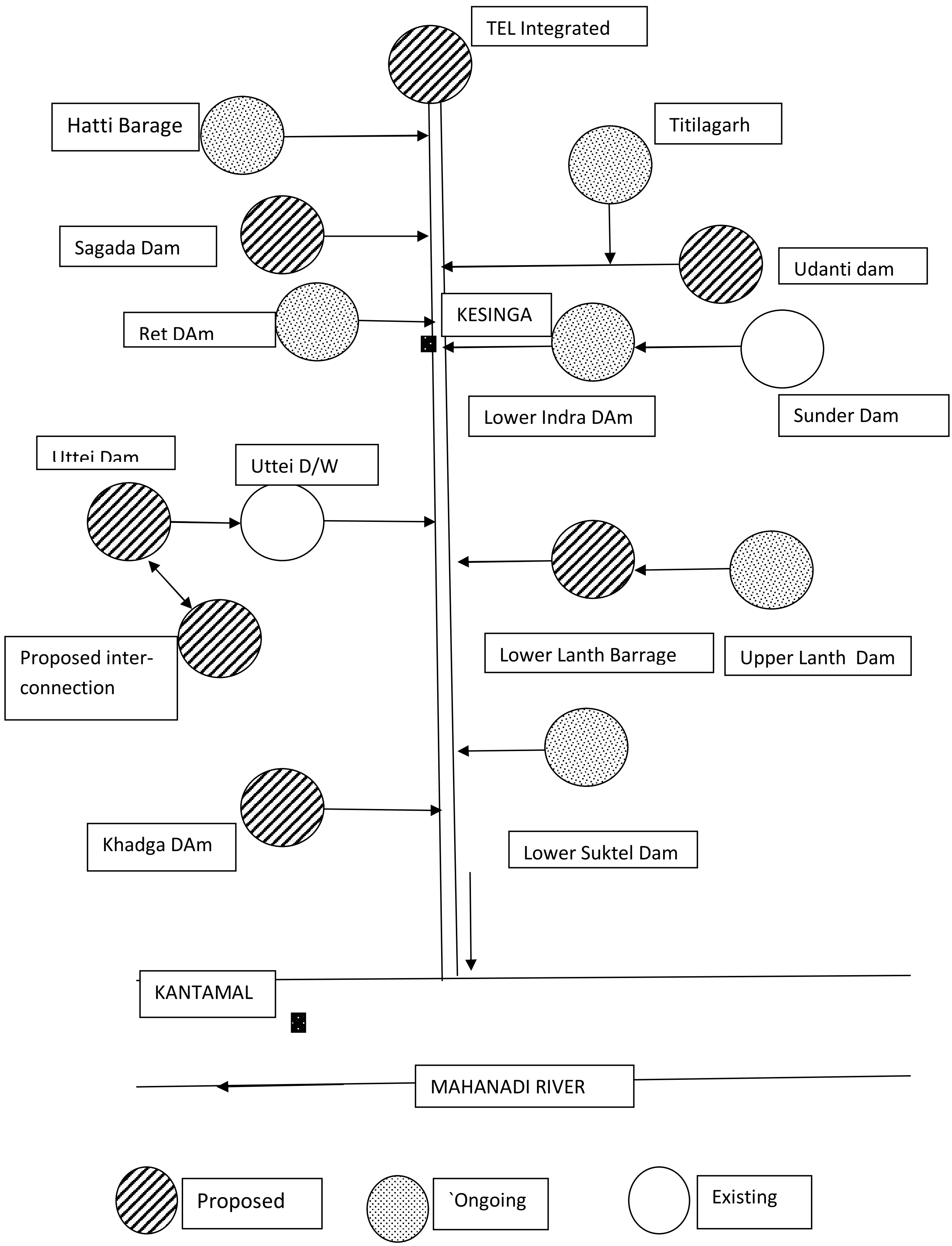


Fig.3. Map and Line diagram of the study area

4. DATA AVAILABILTY:

Data for the two stations Kantamal and Kesinga was available. The Data was collected from the Irrigation Department, Bhubaneswar. For the station Kantamal monthly data was available for the period 1971 till 2009 and for the station Kesinga monthly data was available for the period 1979 till 2008. For data analysis daily average discharge of each month was taken into account. Further, the Indravati power house release discharge data of each day from August 1999 to November 2004 was also collected from the Indravati River Valley project site.

5. STATISTICAL ANALYSIS

5.1. MANN-KENDAL RANK CORRELATION TEST

5.1.1. PROCEDURE

The Mann-Kendall test is a non-parametric test for identifying trends in time series data. The test compares the relative magnitudes of sample data rather than the data values themselves (Gilbert, 1987). One benefit of this test is that the data need not conform to any particular distribution. Moreover, data reported as non-detects can be included by assigning them a common value that is smaller than the smallest measured value in the data set. The procedure that will be described in the subsequent paragraphs assumes that there exists only one data value per time period. When multiple data points exist for a single time period, the median value is used.

5.1.2. MANN-KENDAL STATISTIC (S)

The data values are evaluated as an ordered time series. Each data value is compared to all subsequent data values. The initial value of the Mann-Kendall statistic, S, is assumed to be 0 (*e.g.*, no trend). If a data value from a later time period is higher than a data value from an earlier time period, S is incremented by 1. On the other hand, if the data value from a later time period is lower than a data value sampled earlier, S is decremented by one. Let x_1, x_2,...x_n represent n data points where x_j represents the data point at time j. Then the Mann-Kendall statistic(S) is given by:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign(x_j - x_k)$$

where:

$$sign(x_j - x_k) = 1 \text{ if } x_j - x_k > 0$$

$$= 0 \text{ if } x_j - x_k = 0$$

$$= -1 \text{ if } x_j - x_k < 0$$

A very high positive value of *S* is an indicator of an increasing trend, and a very low negative value indicates a decreasing trend. However, it is necessary to compute the probability associated with S and the sample size, n, to statistically quantify the significance of the trend. The procedure to compute this probability will be described in Section 2.3.

5.1.3. VARIANCE

$$VAR(S) = \frac{1}{18}[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p (t_p - 1)(2t_p + 5)]$$

where n is the number of data points, g is the number of tied groups (a tied group is a set of sample data having the same value), and t_P is the number of data points in the p^{th} group.

5.1.4. EFFECT OF SERIAL CORRELATION (AUTOCORRELATION)

The effect of auto-correlation in the series was taken into account by increasing the variance by a factor given by Wigley and Jones (1981):

$$f^2(N,r) = \frac{1+r}{1-r} - \frac{2r(1-r^N)}{N(1-r)^2}$$

Where r is lag-1 autocorrelation; and N is number of data points. Table 5.1 gives values of lag-1 auto correlation coefficients (r_1) and the corresponding factors (f) for each month from 1971-2009.

Table 5.1. Correlation coefficient and corresponding variance factor

	r_1	f
JAN	0.2558	1.2896
FEB	0.4193	1.5423
MAR	0.0248	1.0244
APR	0.3002	1.3512
MAY	0.3238	1.3858
JUNE	-0.1053	0.9022
JULY	-0.0614	0.9419
AUG	-0.0384	0.9633
SEP	-0.2600	0.7719
OCT	-0.0614	0.9419
NOV	-0.0572	0.9457
DEC	0.3612	1.4437

5.1.5. NORMALIZED TEST STATISTIC Z

$$Z = \frac{S+1}{[VAR(S)^{1/2}} \ if\ S > 0$$

$$= 0\ if\ S = 0$$

$$Z = \frac{S+1}{[VAR(S)^{1/2}} \ if\ S > 0$$

5.1.6. PROBABILITY FUNCTION:

Compute the probability associated with this normalized test statistic. The probability density function for a normal distribution with a mean of 0 and a standard deviation of 1 is given by the following equation:

$$f(z) = \frac{1}{\sqrt{2\pi}} e^{-\frac{z^2}{2}}$$

Microsoft Excel function, NORMSDIST ( ), was used to calculate this probability. A probability level of significance (95% typically) was decided upon.

5.1.7. INFERENCE OF TREND

The trend is said to be decreasing if Z is negative and the computed probability is greater than the level of significance. The trend is said to be increasing if the Z is positive and the computed probability is greater than the level of significance. If the computed probability is less than the level of significance, there is no trend.

5.2. ASSUMPTIONS

When multiple samples were collected on a single day, the median value of all those samples was assumed to be the representative sample. It was assumed that the variation in the sampling depths was not large enough to produce a bias in the trend statistics.

5.3. EEFECT OF SERIAL CORRELATION (AUTOCORRELATION)

A serial correlation is the association between the successive terms in the same series x_t by lagging them suitably as per the requirement. The method of calculation of correlation coefficient between two variables (x_i, y_i) can be extended to the individual series of either x_i or y_i lagged by k distance apart. As an example for a runoff series of n periods, it may be desired to find the relation or dependence between the same series with lag or spacing of say k time apart. The correlation is referred to as autocorrelation.

It gives an idea of the dependence or association between the values of the same series. When k is taken as one and the event represents the magnitude of monthly runoff, then the serial correlation defines the association or dependence between the consecutive monthly values of the time series. This shows the effect of the flow of June on July, July on August and so on for the lag of k=1 unit of time. The following simplified equation can be used to obtain the serial correlation co-efficient of lag or spacing k time apart.

$$r_k = \frac{\frac{1}{n-k}\sum X_i X_{i+k} - \frac{1}{(n-k)^2}\sum X_i \sum X_{i+1}}{\{\frac{1}{n-k}\sum X_i^2 - \frac{1}{(n-k)^2}(\sum X_i)^2\}^{1/2}\ \{\frac{1}{n-k}\sum X_{i+k}^2 - \frac{1}{(n-k)^2}(\sum X_{i+k})^2\}^{1/2}}$$

in which n is the length of the data, k the lag distance in the serial correlation, x_i is the variate. The summation should be carried out from i=1 to n-k. For k = 0, the correlation co-efficient r_0=1 and for other values of k, the value of r lies between ± 1 . If the series is random r_k=0 for all lags of k.

A plot between the lags k in abscissa against the serial correlation r_k is defined as *correlagram.* At 95% significance level, a tolerance band in either side of the plotted points (of r_k vs. k) can be drawn.

6. METHODOLOGY

- Initially, the graphs were plotted in EXCEL using the INSERT GRAPH command. Yearly, monthly and daily graphs were plotted.
- Then the mean of the monthly values of discharge for both the stations were found out using the function AVERAGE ( ).
- For the Kantamal site graphs were plotted from the year 1971-2009.
- LINEST ( ) function was used to fit a Linear Trend Line for designing Predictive model which uses the Least Squares Method.
- Predictive Models for Kantamal site was designed using LINEST ( ) from the year 1971 to 2009.

7. DATA ANALYSIS

- The observed daily discharge values are tabulated in Table 8.1 from the year 1971-2009.
- The Indravati Power House Release discharge (Table 8.2) was subtracted from the observed discharge values.
- The filtrated values are tabulated in Table 8.3 and the negative data values so obtained if any is replaced by zero, since physically discharge of a river cannot be negative.
- Histograms of observed and filtrated values are plotted for each month using the new values of discharge.
- Another analysis was done by using the new results. The highest negative value was made zero and the Indravati power discharge value was changed.
- Using this new value of Indravati Power discharge, this value was subtracted from the observed values to get new set of data.
- Graphs are plotted using the new set of data for each month (Chapter 10).

8. TABULATIONS:

Table 8.1. KANTAMAL DAILY OBSERVED DISCHARGE

	JAN	***FEB***	***MAR***	***APR***	***MAY***	***JUNE***	***JULY***	***AUG***	***SEP***	***OCT***	***NOV***	***DEC***
1971	-	-	-	-	-	0.00	0.00	711.27	611.89	276.47	133.79	54.46
1972	19.73	12.93	4.90	2.26	0.60	9.90	840.95	574.95	1221.66	121.97	69.05	52.96
1973	17.51	7.67	4.12	0.75	0.08	17.82	2067.56	1074.70	1078.04	1021.49	281.35	52.84
1974	19.60	8.52	3.14	0.97	0.92	50.43	125.50	526.97	503.85	83.28	23.61	16.08
1975	2.97	5.53	0.40	0.37	0.09	136.29	509.00	979.56	600.28	217.38	127.79	46.87
1976	11.21	5.00	0.61	0.28	1.32	8.50	885.86	2004.97	1061.67	71.61	35.34	23.52
1977	8.46	2.98	0.88	0.77	14.17	21.03	518.10	1200.05	2009.71	114.93	85.93	43.02
1978	16.46	12.48	6.87	3.38	1.53	20.09	596.59	3783.77	683.82	154.39	129.90	44.97
1979	16.89	10.50	3.17	0.67	0.15	299.32	574.44	907.08	110.21	189.47	30.02	14.32
1980	8.69	2.68	0.71	0.40	0.00	263.28	1600.46	545.58	2091.23	128.12	57.71	34.81
1981	23.29	10.36	10.66	4.68	3.13	9.71	49.98	1529.39	687.08	198.10	68.98	32.11
1982	11.29	6.00	9.87	2.95	1.88	28.48	289.18	1112.14	524.06	49.61	37.16	17.06
1983	5.89	9.00	2.67	6.05	2.82	80.19	267.41	801.90	727.09	336.68	82.25	39.30
1984	11.71	5.40	1.33	5.31	0.97	336.83	1103.84	1264.68	364.67	67.85	33.83	20.89
1985	16.15	6.33	1.43	0.14	4.45	127.50	766.75	2146.11	2677.88	576.69	242.05	66.54
1986	25.35	18.53	5.71	2.21	5.01	792.32	1346.01	1272.73	266.24	189.94	69.65	31.69
1987	17.92	5.56	1.81	0.29	3.94	18.53	317.03	173.09	494.42	84.74	131.80	38.51
1988	6.58	4.73	3.28	0.43	0.88	90.92	227.09	390.09	426.44	157.21	38.67	19.84
1989	3.33	0.58	0.00	0.00	0.00	238.34	384.03	757.55	544.09	145.94	52.20	25.49
1990	7.31	4.71	8.24	3.56	94.56	251.95	1068.26	1777.35	1889.25	2206.57	700.24	109.14
1991	55.91	21.54	12.02	7.32	4.40	34.80	1577.80	2597.39	699.55	310.74	191.54	61.19
1992	29.11	16.49	8.29	4.43	2.02	321.09	1626.41	2088.28	661.09	123.16	64.00	33.54
1993	15.25	7.57	3.24	1.59	1.43	103.31	681.72	1189.18	753.61	252.98	118.10	45.67
1994	15.11	13.72	2.80	2.49	0.55	352.11	1748.88	3001.75	2183.27	276.75	124.25	70.28
1995	77.58	21.16	9.15	6.71	163.39	72.57	1104.28	985.36	818.26	313.02	300.72	79.93
1996	38.59	17.63	11.07	6.54	3.13	9.70	133.71	834.70	317.46	82.71	16.73	19.82
1997	16.88	6.74	1.00	8.96	4.07	20.50	140.56	2280.77	864.32	144.07	97.09	102.25
1998	36.55	27.41	19.25	12.64	14.34	24.61	341.98	306.44	309.81	162.13	152.47	43.30
1999	13.45	3.87	0.43	0.00	9.46	24.23	369.78	627.85	713.21	305.01	146.78	70.84
2000	51.57	40.58	39.54	34.00	71.40	99.28	545.49	451.40	486.31	200.70	148.27	108.92
2001	80.65	73.22	66.57	71.62	76.59	1244.53	3344.90	2202.22	582.05	283.30	219.30	168.37
2002	120.69	123.70	143.49	72.59	26.93	92.51	67.27	574.82	496.28	51.19	42.26	38.16
2003	18.19	11.17	16.53	41.15	73.06	70.31	555.21	1899.60	1540.07	766.21	258.69	205.46
2004	141.50	99.64	82.42	86.96	81.83	936.94	631.85	1297.48	486.45	553.27	318.45	158.20
2005	92.13	81.34	41.20	35.61	74.14	95.18	544.31	467.69	1393.45	297.70	141.75	109.24
2006	84.27	91.48	79.87	90.77	128.35	167.33	1774.36	3600.13	1112.10	571.62	232.97	123.08
2007	66.12	53.50	47.56	53.83	103.34	332.40	908.72	2239.80	1570.63	554.85	170.84	165.15
2008	143.40	92.81	54.26	38.65	34.98	139.73	395.67	2490.13	2880.87	307.77	144.58	113.83
2009	74.10	76.76	81.98	50.42	31.09	-	-	-	-	-	-	-

Table 8.2. INDRAVATI POWER HOUSE RELEASE

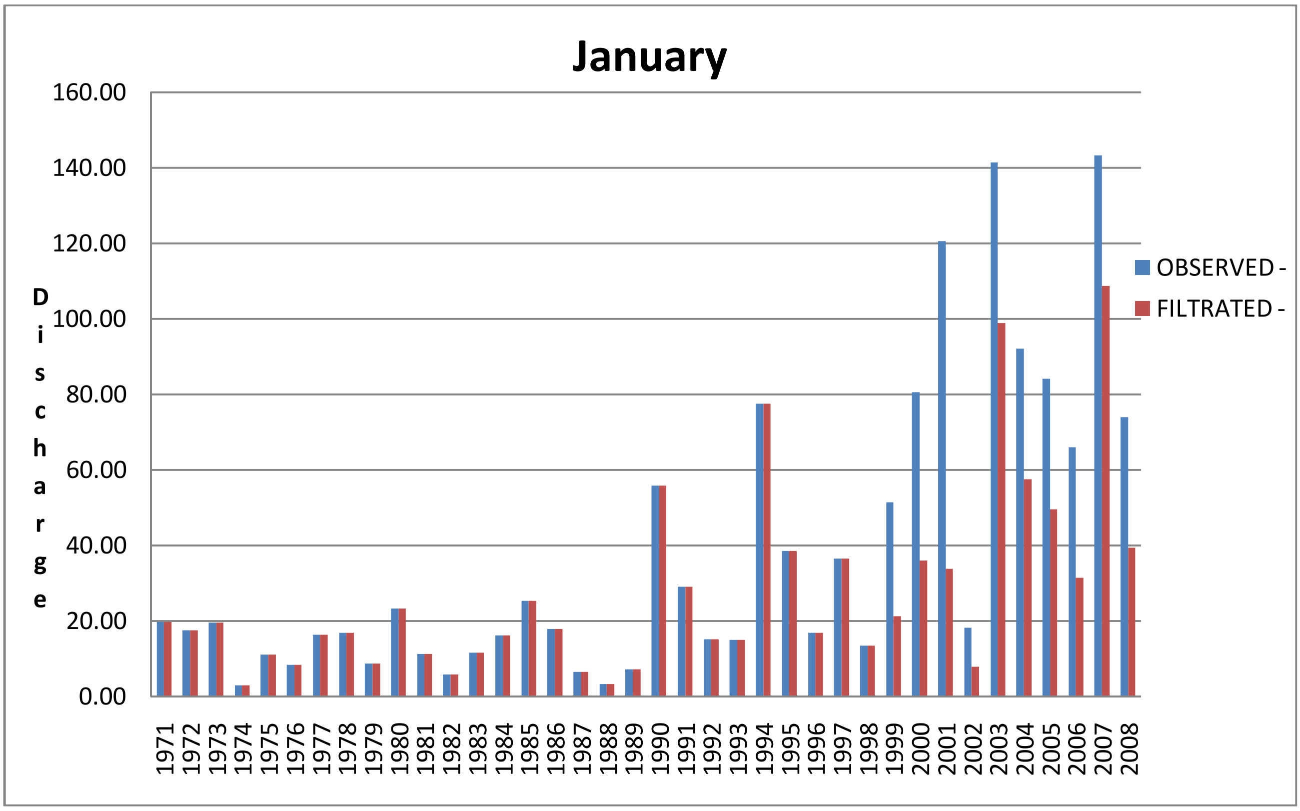
	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1999	0	0	0	0	0	0	0	0	3.62	0.00	10.20	8.36
2000	30.27	19.21	19.78	33.54	0.00	14.27	19.14	10.69	29.84	43.30	11.12	24.24
2001	44.50	43.20	47.89	46.49	7.86	0.00	0.00	0.00	38.46	56.13	10.47	0.00
2002	86.80	80.25	85.08	28.60	9.25	0.00	27.79	9.64	16.55	30.34	13.58	0.00
2003	10.27	10.47	15.97	28.27	0.94	0.00	24.16	14.87	44.25	61.15	10.41	0.00
2004	42.56	42.50	73.64	64.79	8.21	7.64	74.59	57.63	81.29	69.48	35.15	0.00
2005	34.58	35.09	39.25	33.62	0.00	3.40	20.87	14.97	37.40	42.00	4.31	9.22
2006	34.58	35.09	39.25	33.62	0.00	3.40	20.87	14.97	37.40	42.00	4.31	9.22
2007	34.58	35.09	39.25	33.62	0.00	3.40	20.87	14.97	37.40	42.00	4.31	9.22
2008	34.58	35.09	39.25	33.62	0.00	3.40	20.87	14.97	37.40	42.00	4.31	9.22
2009	34.58	35.09	39.25	33.62	0.00	3.40	20.87	14.97	37.40	42.00	4.31	9.22

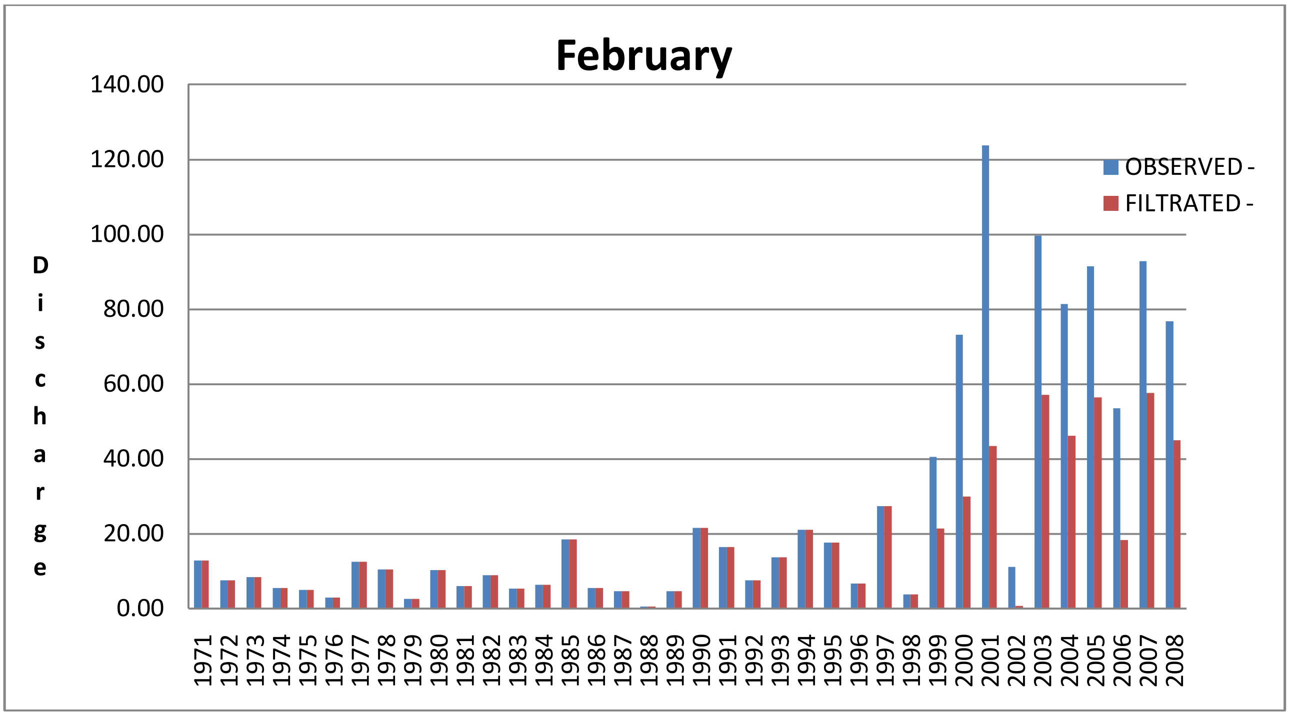
Fig.4. Indravati River Valley Project

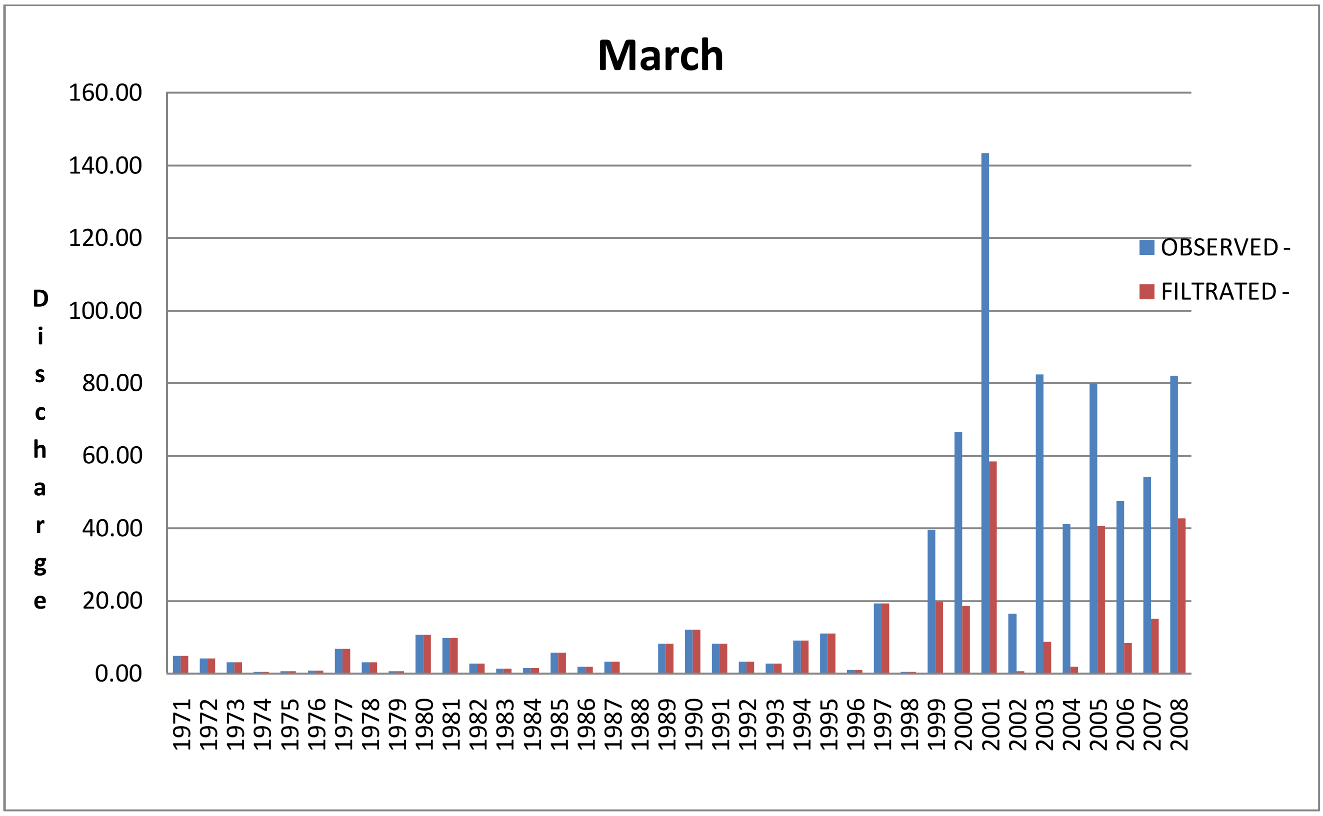
Table 9.3. KANTAMAL FILTRATED DAILY DISCHARGE

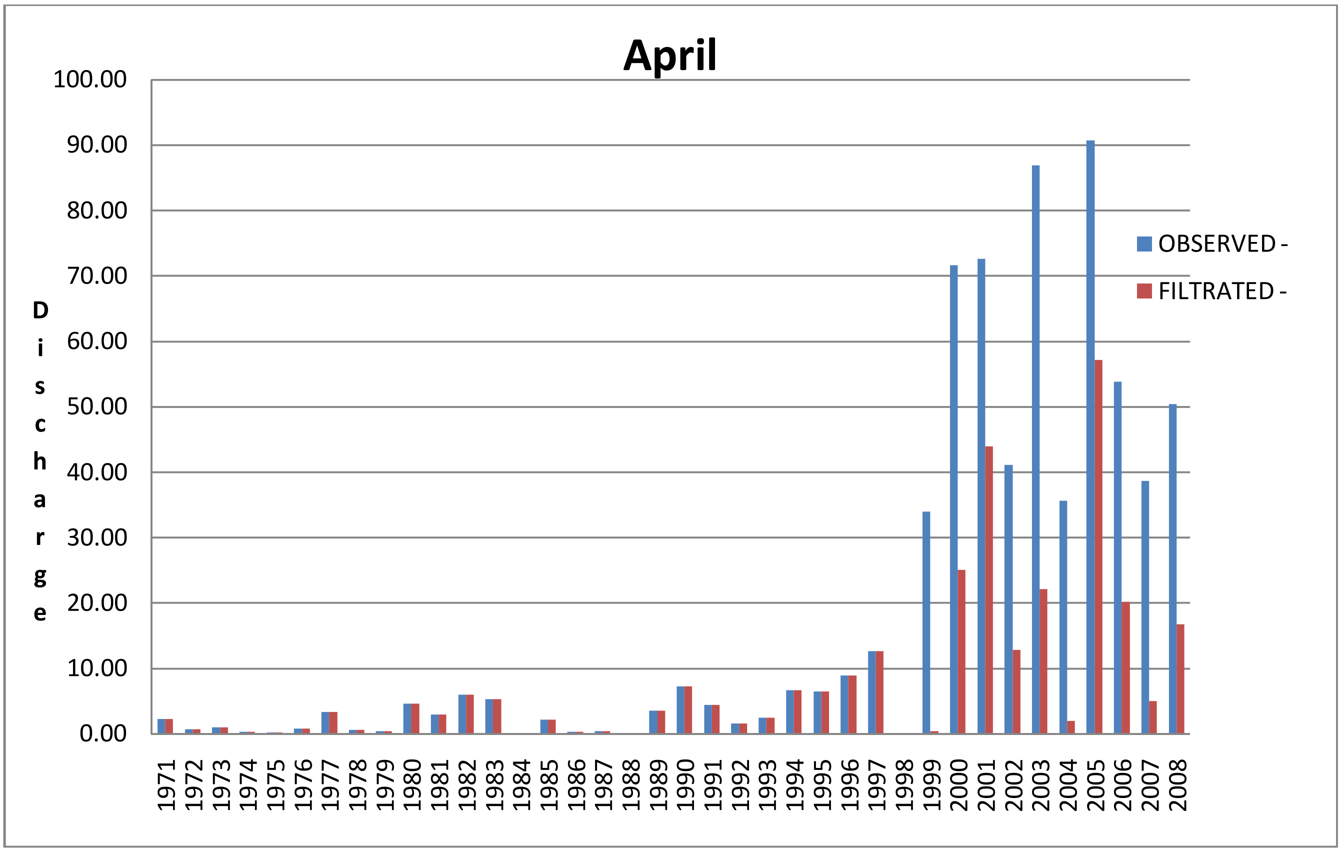
	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
1971	-	-	-	-	-	0.00	0.00	711.27	611.89	276.47	133.79	54.46
1972	19.73	12.93	4.90	2.26	0.60	9.90	840.95	574.95	1221.66	121.97	69.05	52.96
1973	17.51	7.67	4.12	0.75	0.08	17.82	2067.56	1074.70	1078.04	1021.49	281.35	52.84
1974	19.60	8.52	3.14	0.97	0.92	50.43	125.50	526.97	503.85	83.28	23.61	16.08
1975	2.97	5.53	0.40	0.37	0.09	136.29	509.00	979.56	600.28	217.38	127.79	46.87
1976	11.21	5.00	0.61	0.28	1.32	8.50	885.86	2004.97	1061.67	71.61	35.34	23.52
1977	8.46	2.98	0.88	0.77	14.17	21.03	518.10	1200.05	2009.71	114.93	85.93	43.02
1978	16.46	12.48	6.87	3.38	1.53	20.09	596.59	3783.77	683.82	154.39	129.90	44.97
1979	16.89	10.50	3.17	0.67	0.15	299.32	574.44	907.08	110.21	189.47	30.02	14.32
1980	8.69	2.68	0.71	0.40	0.00	263.28	1600.46	545.58	2091.23	128.12	57.71	34.81
1981	23.29	10.36	10.66	4.68	3.13	9.71	49.98	1529.39	687.08	198.10	68.98	32.11
1982	11.29	6.00	9.87	2.95	1.88	28.48	289.18	1112.14	524.06	49.61	37.16	17.06
1983	5.89	9.00	2.67	6.05	2.82	80.19	267.41	801.90	727.09	336.68	82.25	39.30
1984	11.71	5.40	1.33	5.31	0.97	336.83	1103.84	1264.68	364.67	67.85	33.83	20.89
1985	16.15	6.33	1.43	0.14	4.45	127.50	766.75	2146.11	2677.88	576.69	242.05	66.54
1986	25.35	18.53	5.71	2.21	5.01	792.32	1346.01	1272.73	266.24	189.94	69.65	31.69
1987	17.92	5.56	1.81	0.29	3.94	18.53	317.03	173.09	494.42	84.74	131.80	38.51
1988	6.58	4.73	3.28	0.43	0.88	90.92	227.09	390.09	426.44	157.21	38.67	19.84
1989	3.33	0.58	0.00	0.00	0.00	238.34	384.03	757.55	544.09	145.94	52.20	25.49
1990	7.31	4.71	8.24	3.56	94.56	251.95	1068.26	1777.35	1889.25	2206.57	700.24	109.14
1991	55.91	21.54	12.02	7.32	4.40	34.80	1577.80	2597.39	699.55	310.74	191.54	61.19
1992	29.11	16.49	8.29	4.43	2.02	321.09	1626.41	2088.28	661.09	123.16	64.00	33.54
1993	15.25	7.57	3.24	1.59	1.43	103.31	681.72	1189.18	753.61	252.98	118.10	45.67
1994	15.11	13.72	2.80	2.49	0.55	352.11	1748.88	3001.75	2183.27	276.75	124.25	70.28
1995	77.58	21.16	9.15	6.71	163.39	72.57	1104.28	985.36	818.26	313.02	300.72	79.93
1996	38.59	17.63	11.07	6.54	3.13	9.70	133.71	834.70	317.46	82.71	16.73	19.82
1997	16.88	6.74	1.00	8.96	4.07	20.50	140.56	2280.77	864.32	144.07	97.09	102.25
1998	36.55	27.41	19.25	12.64	14.34	24.61	341.98	306.44	309.81	162.13	152.47	43.30
1999	13.45	3.87	0.43	0.00	9.46	24.23	369.78	627.85	709.59	305.01	136.58	62.48
2000	21.30	21.37	19.76	0.46	71.40	85.01	526.35	440.71	456.47	157.40	137.14	84.69
2001	36.15	30.02	18.67	25.13	68.73	1244.53	3344.90	2202.22	543.59	227.17	208.83	168.37
2002	33.88	43.45	58.41	43.98	17.68	92.51	39.48	565.18	479.73	20.85	28.68	38.16
2003	7.92	0.70	0.56	12.88	72.11	70.31	531.05	1884.73	1495.82	705.06	248.28	205.46
2004	98.95	57.14	8.78	22.17	73.62	929.30	557.26	1239.85	405.15	483.80	283.30	158.20
2005	57.55	46.25	1.95	2.00	74.14	91.78	523.44	452.72	1356.06	255.70	137.43	100.02
2006	49.68	56.39	40.61	57.15	128.35	163.93	1753.49	3585.16	1074.70	529.62	228.66	113.87
2007	31.54	18.41	8.31	20.22	103.34	329.00	887.85	2224.83	1533.23	512.85	166.53	155.93
2008	108.82	57.72	15.01	5.03	34.98	136.33	374.80	2475.16	2843.47	265.77	140.27	104.61
2009	39.52	45.07	43.99	18.98	31.09	-	-	-	-	-	-	-

10. KANTAMAL OBSERVED AND FILTRATED DISCHARGE VALUES






March
Discharge
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
OBSERVED -
FILTRATED -
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008


April
Discharge
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
OBSERVED -
FILTRATED -
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
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1984
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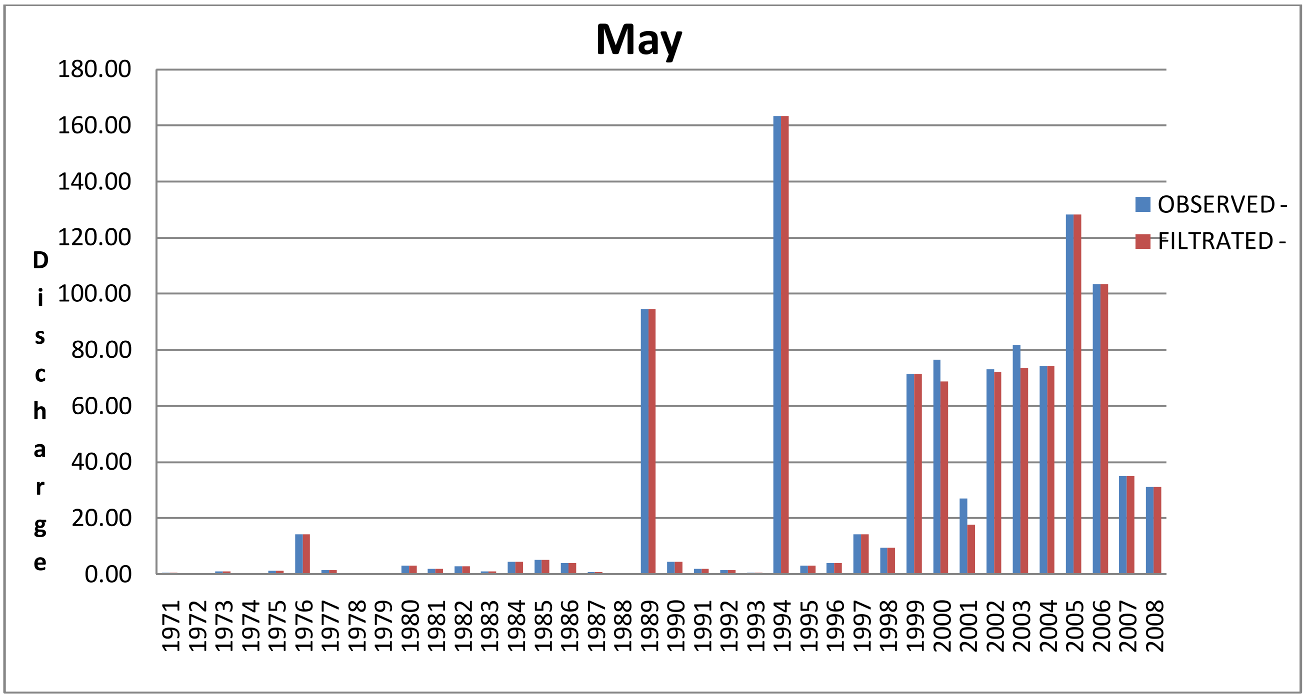
2002
2003
2004
2005
2006
2007
2008


May
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Discharge
OBSERVED -
FILTRATED -
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
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2004
2005
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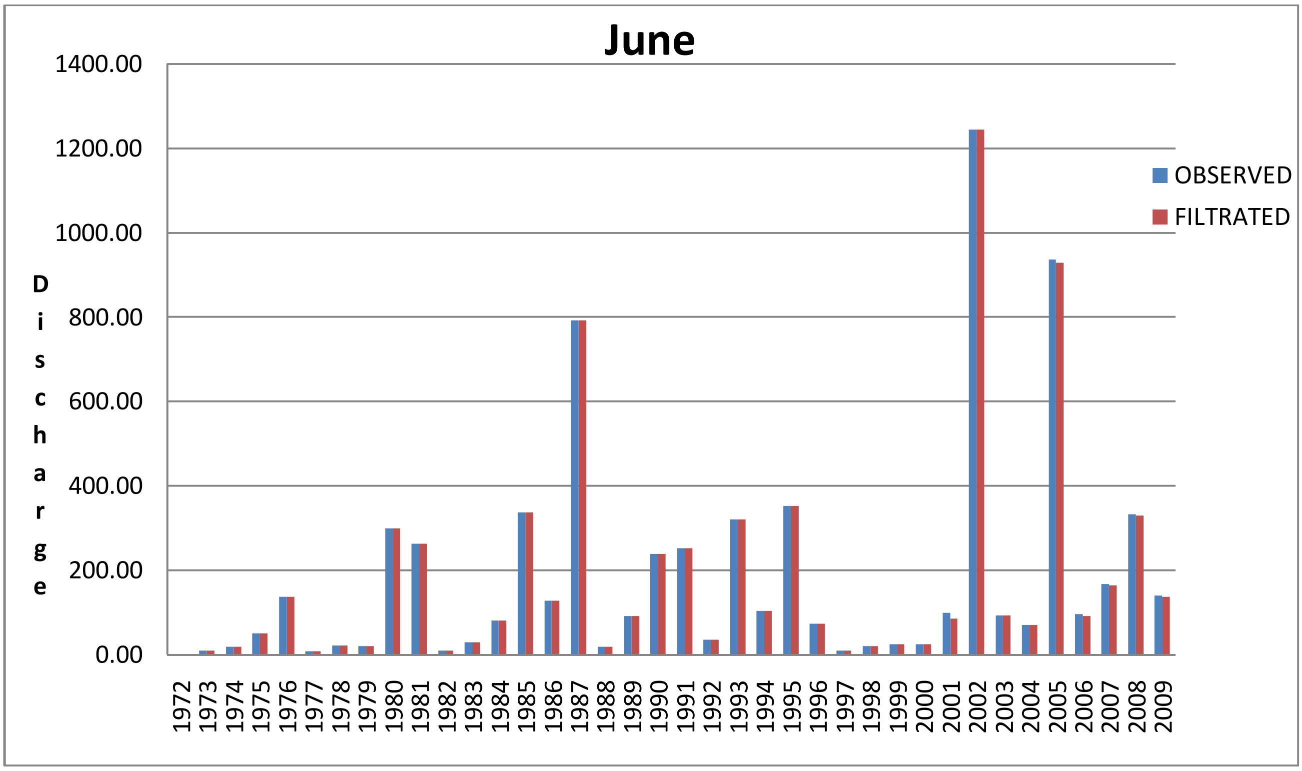
2007
2008


June
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
Discharge
OBSERVED
FILTRATED
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
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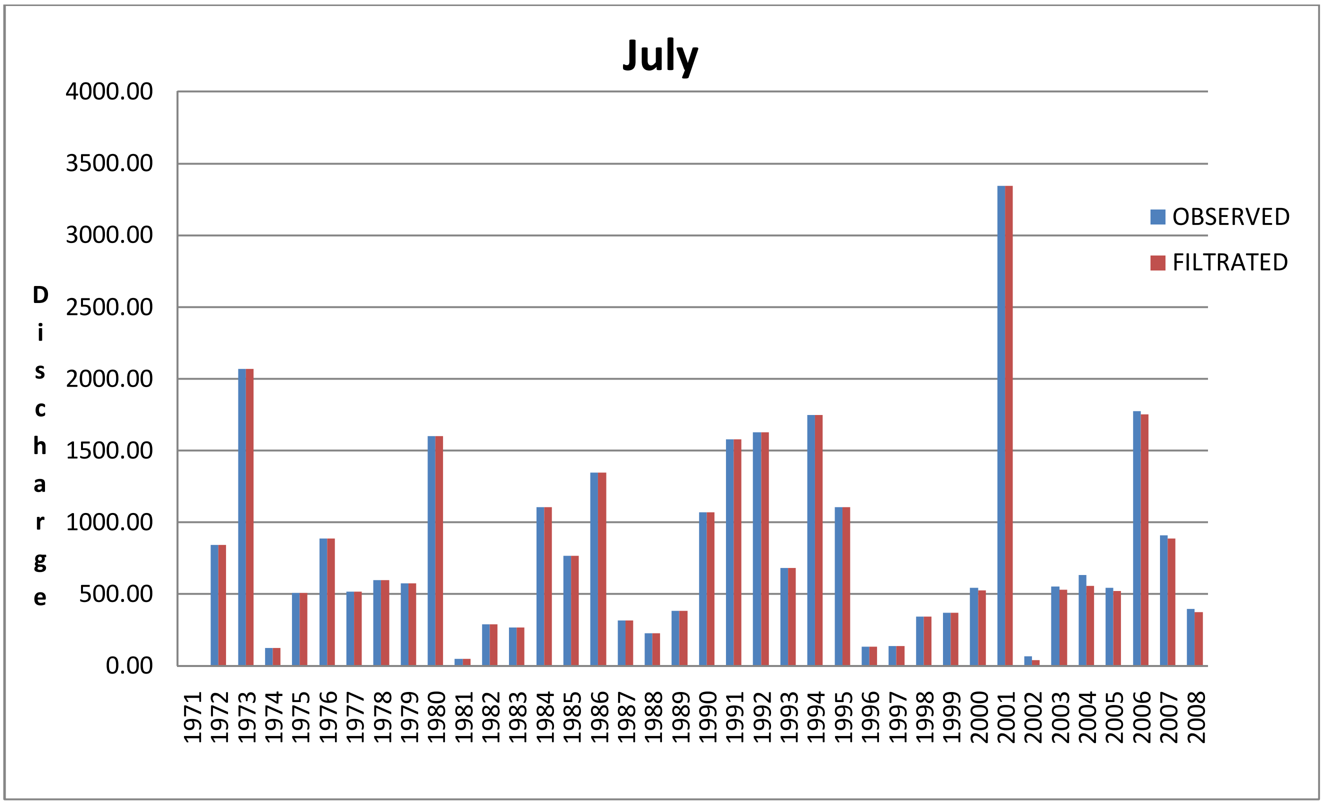
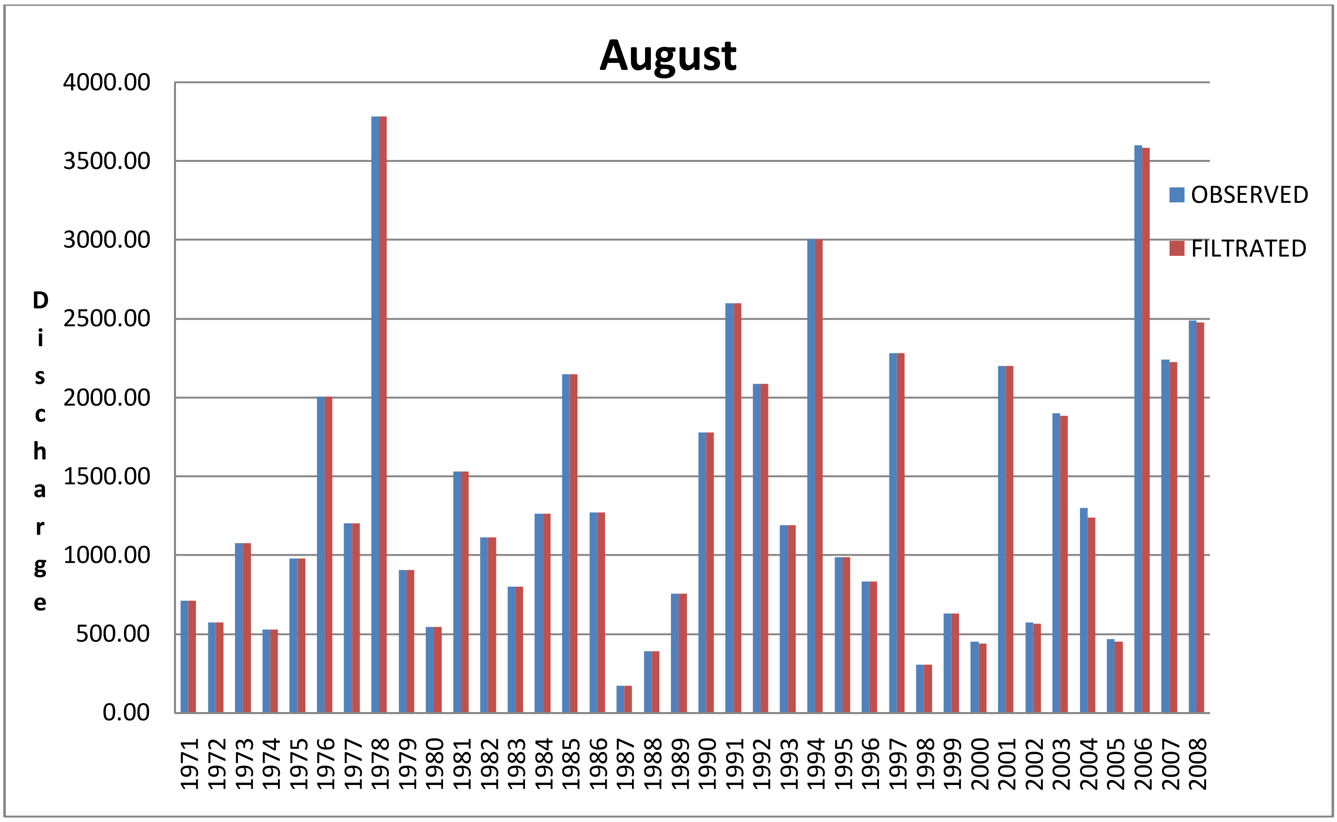
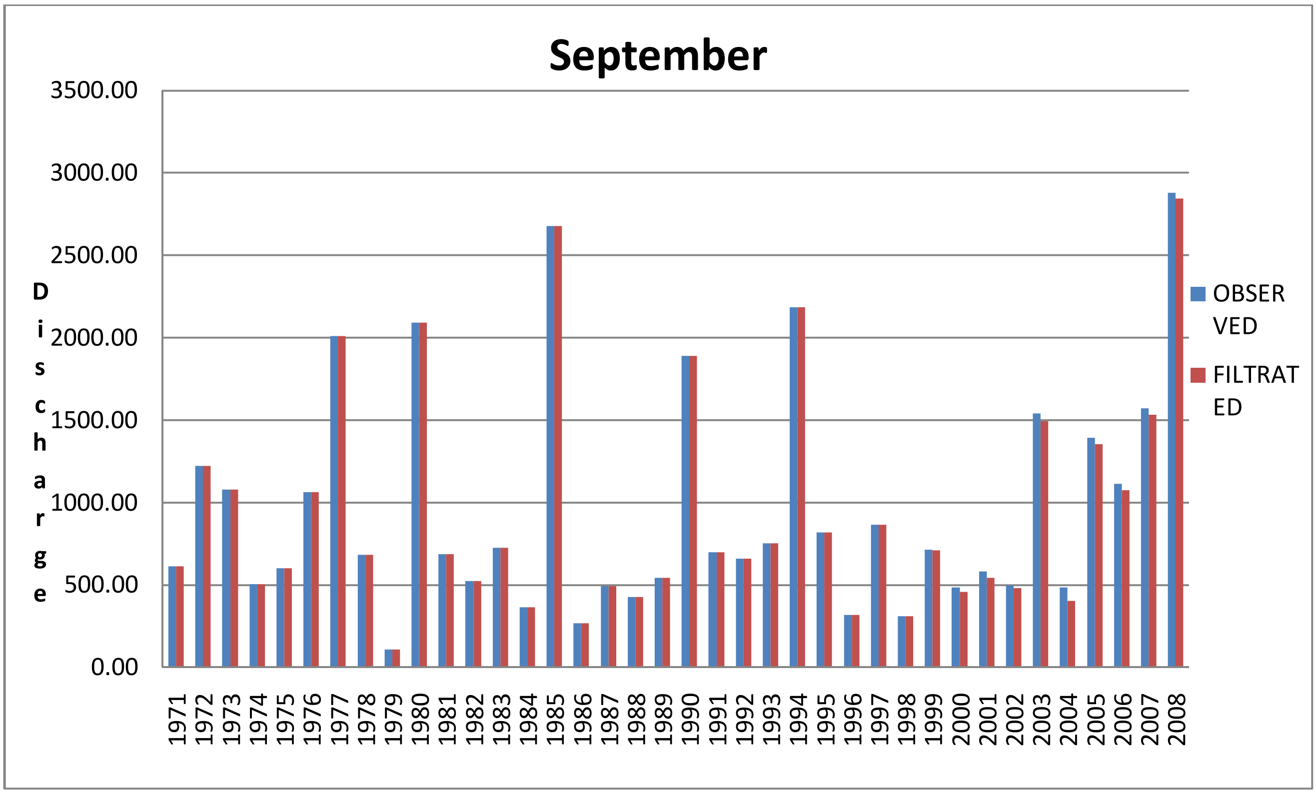
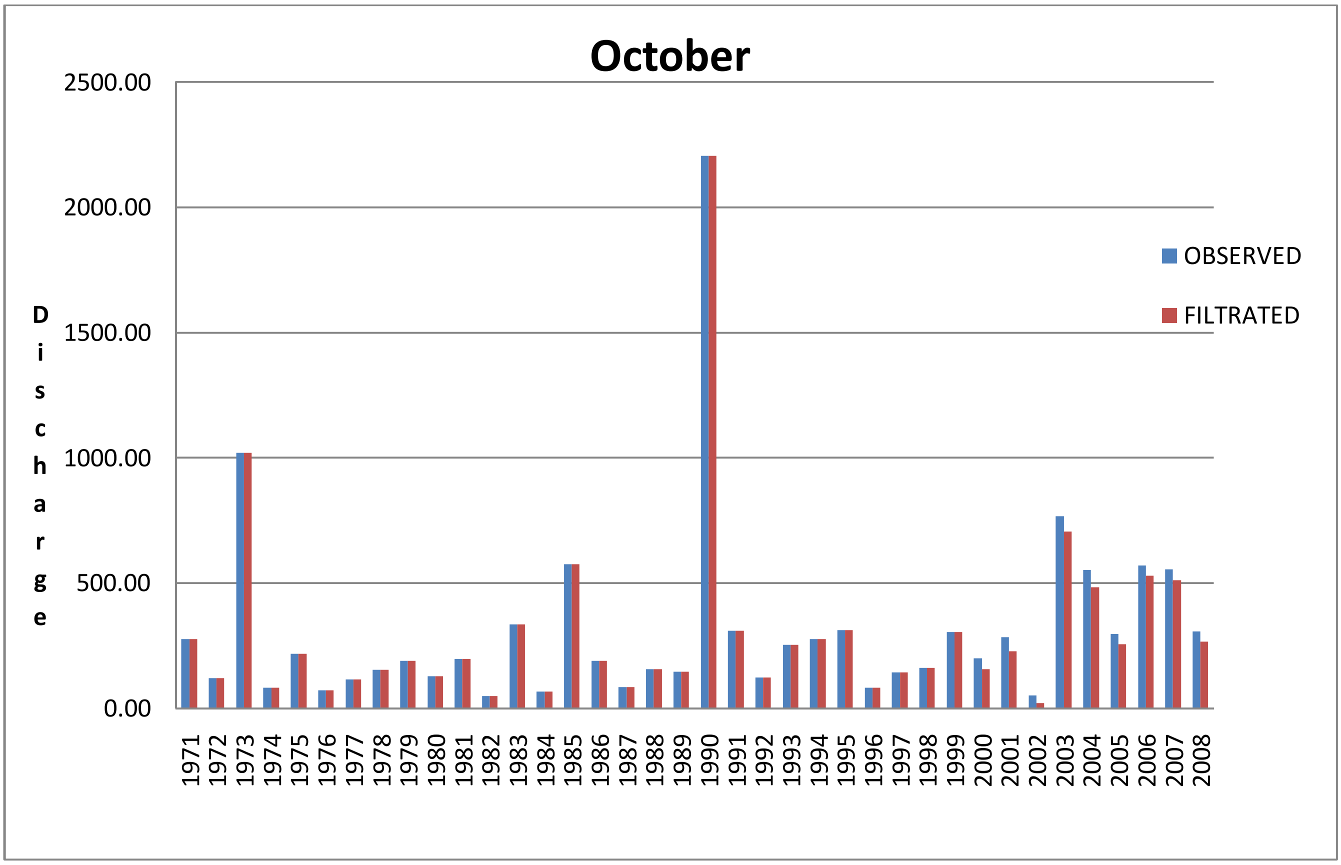
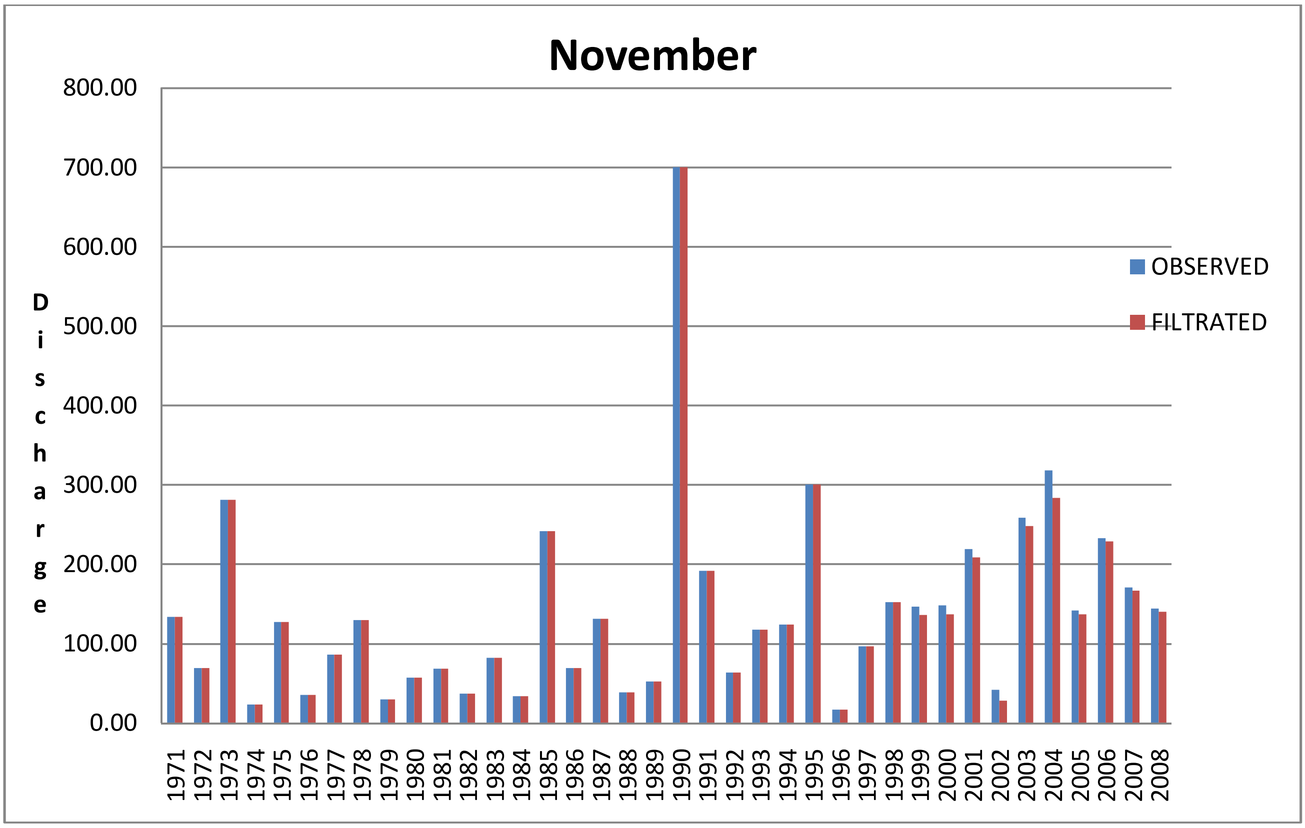
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009


July
4000.00
3500.00
3000.00
2500.00
2000.00
1500.00
1000.00
500.00
0.00
Discharge
OBSERVED
FILTRATED
1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008


August
4000.00
3500.00
3000.00
2500.00
2000.00
1500.00
1000.00
500.00
0.00
Discharge
OBSERVED
FILTRATED
1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008


September
3500.00
3000.00
2500.00
2000.00
1500.00
1000.00
500.00
0.00
Discharge
OBSERVED
FILTRATED
1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008


October
2500.00
2000.00
1500.00
1000.00
500.00
0.00
Discharge
OBSERVED
FILTRATED
1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008


November
800.00
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
Discharge
OBSERVED
FILTRATED
1971
1972
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1974
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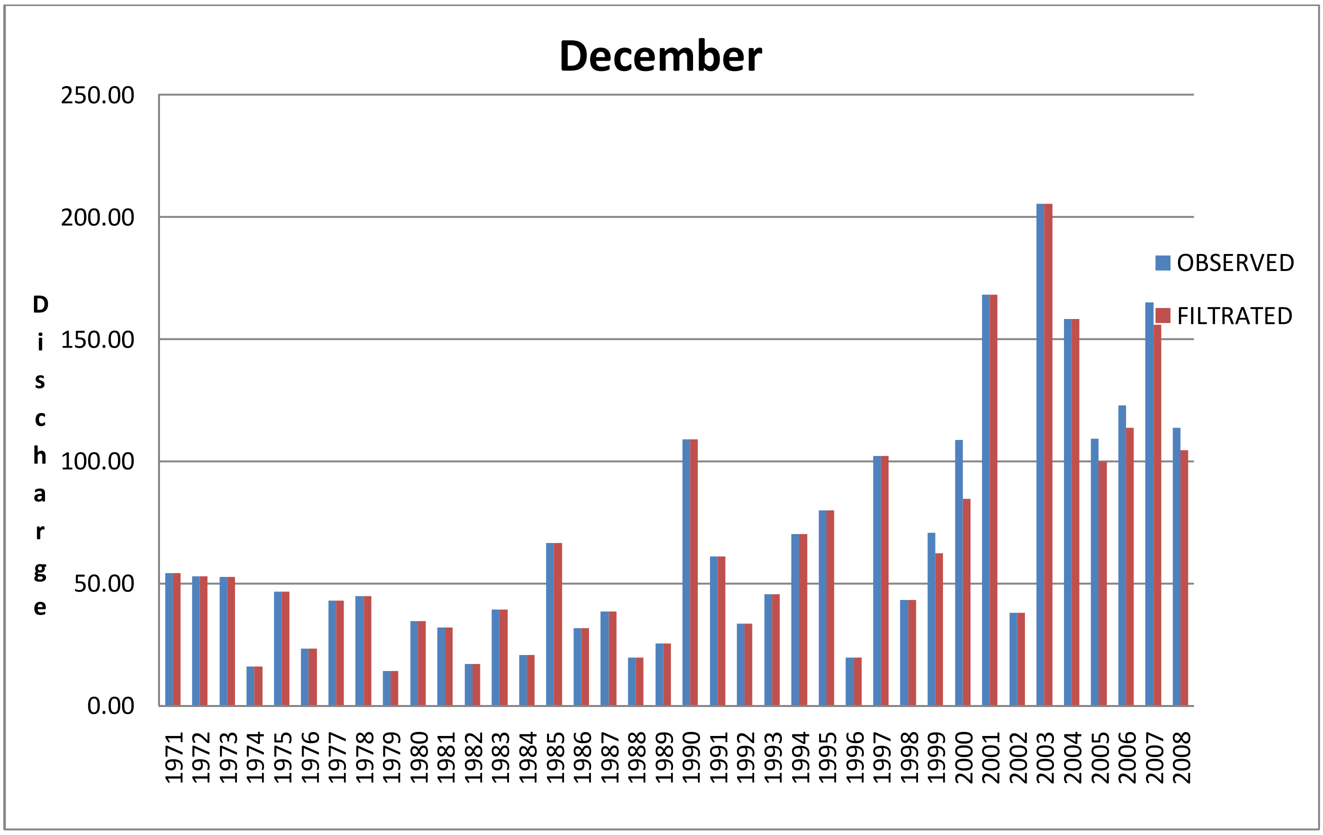
2007
2008


December
250.00
200.00
150.00
100.00
50.00
0.00
Discharge
OBSERVED
FILTRATED
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
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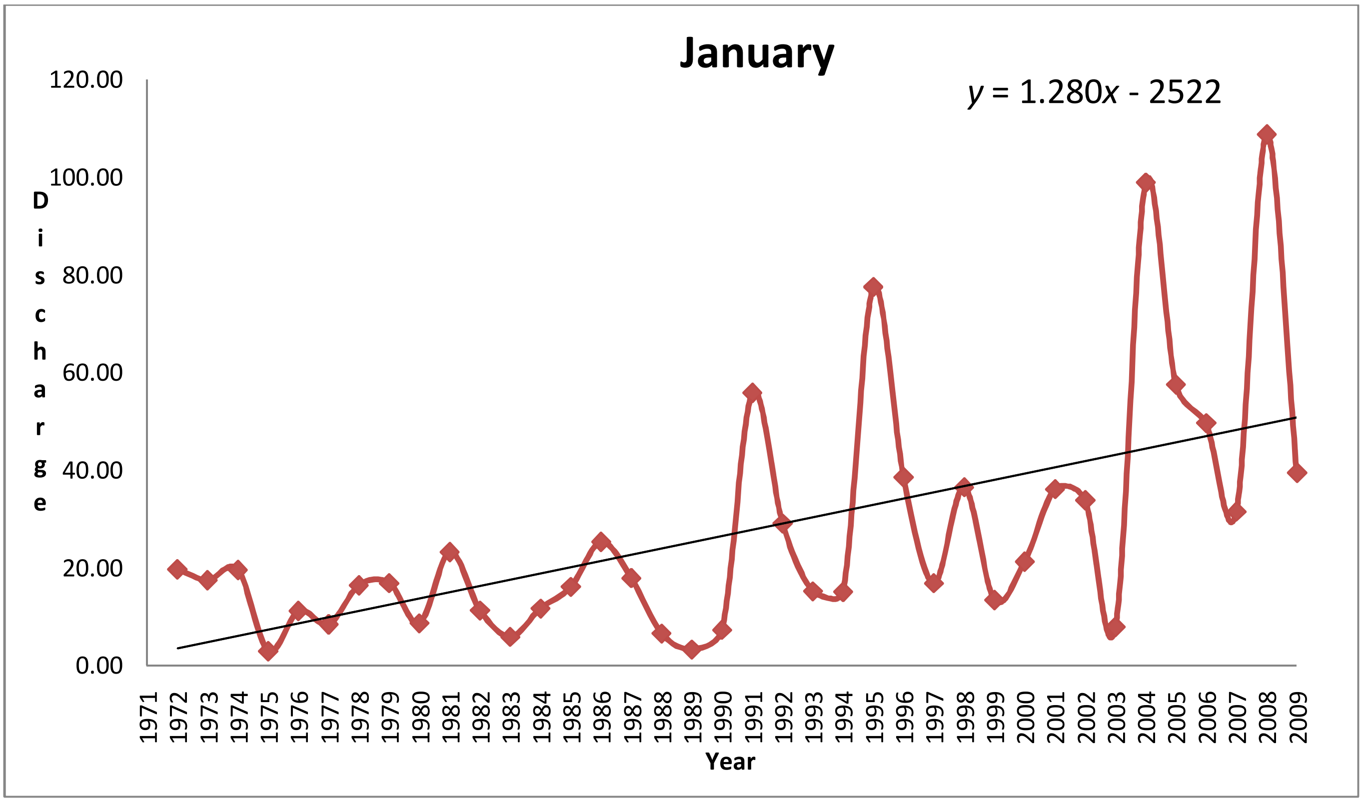
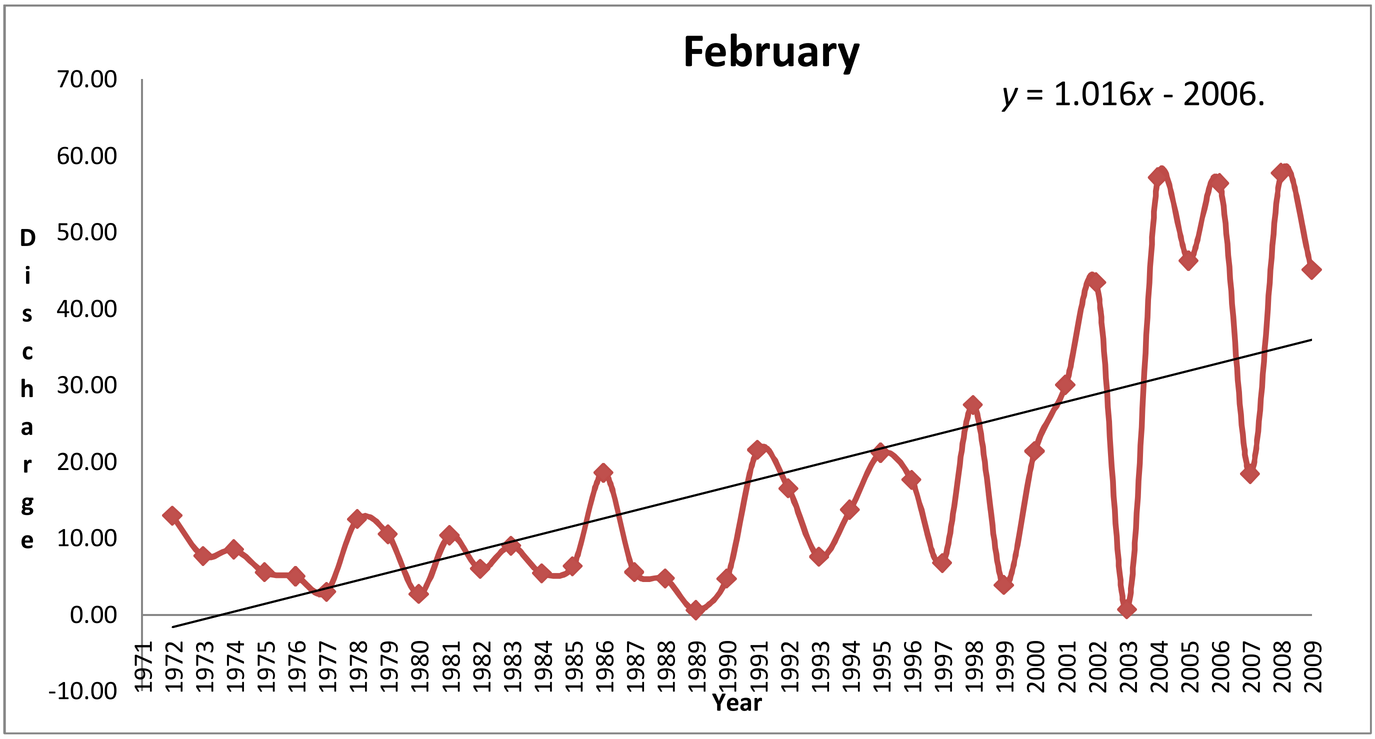
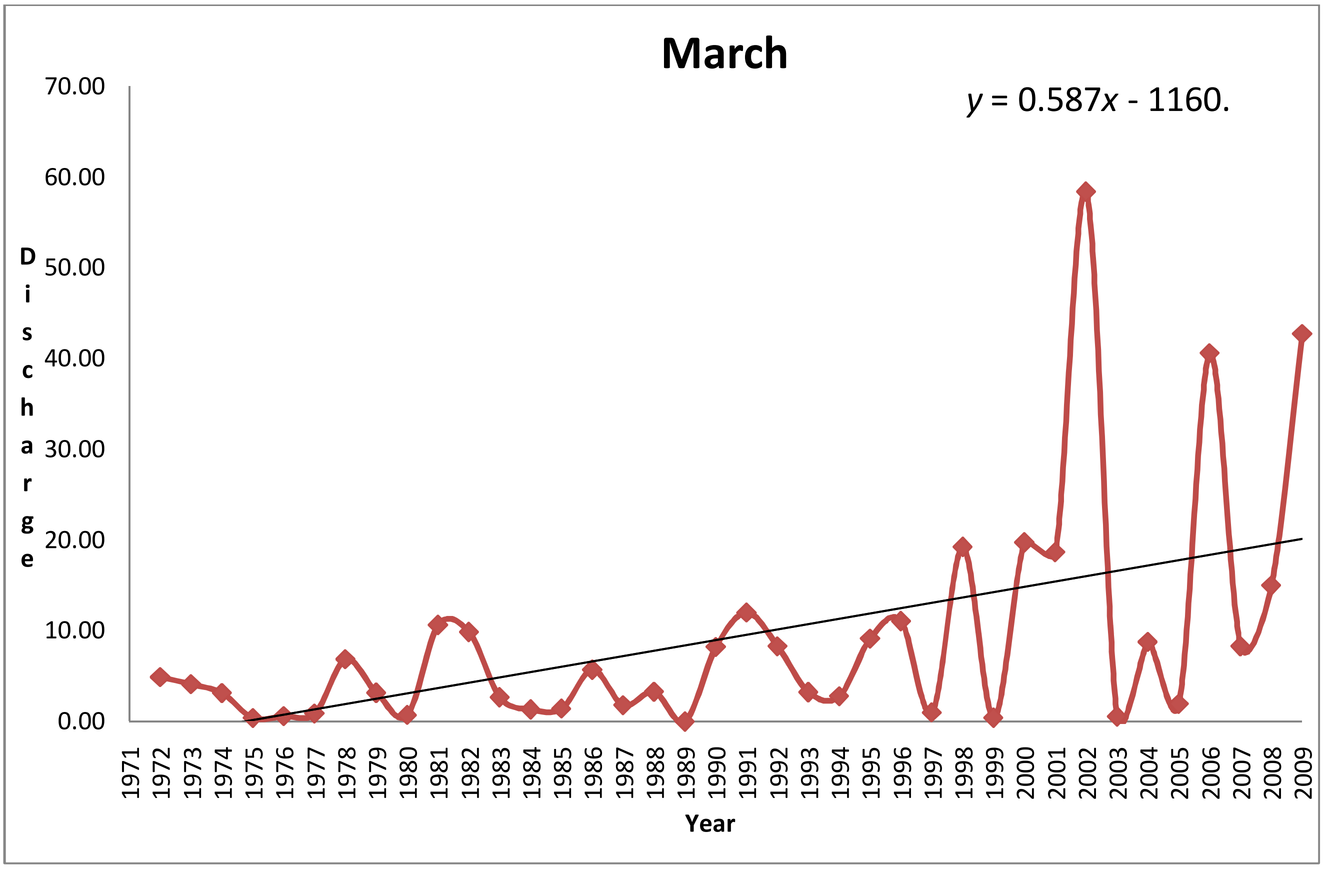
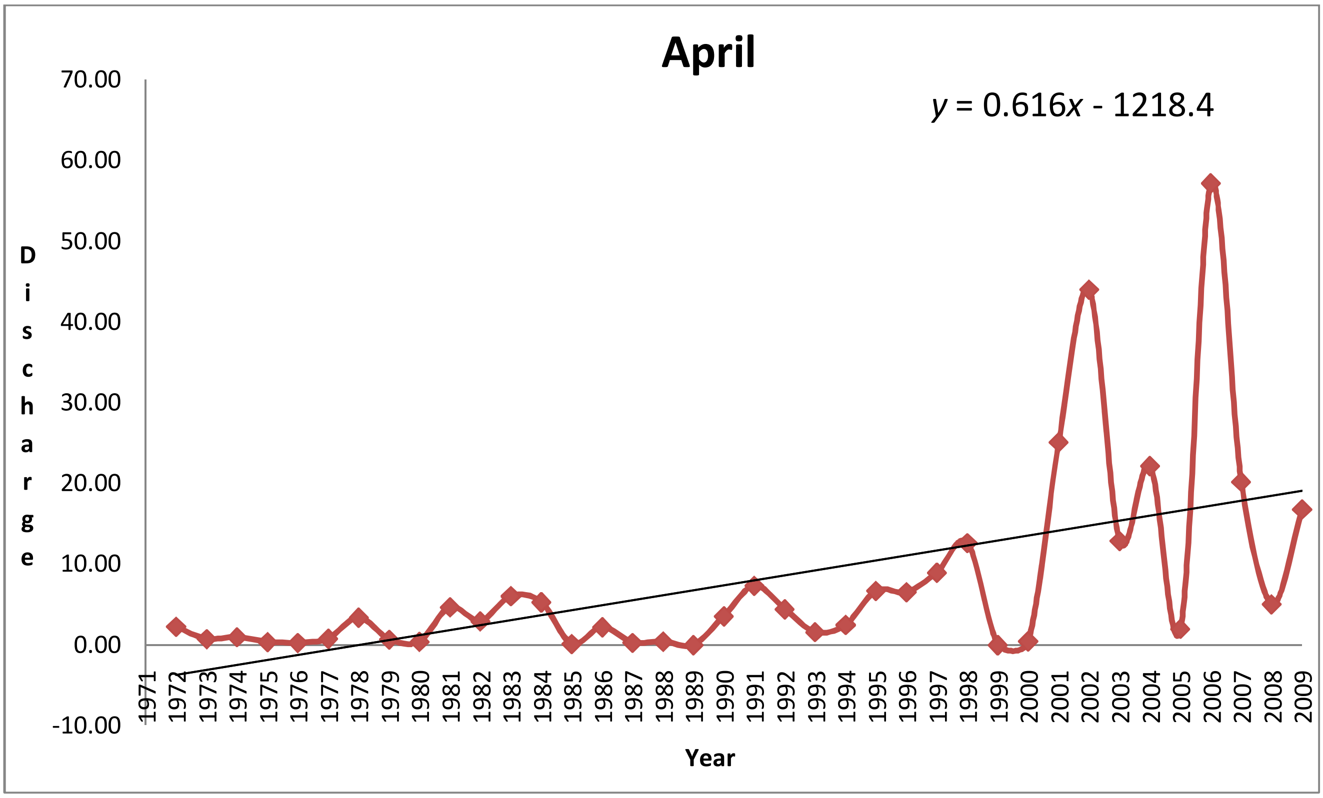
2007
2008

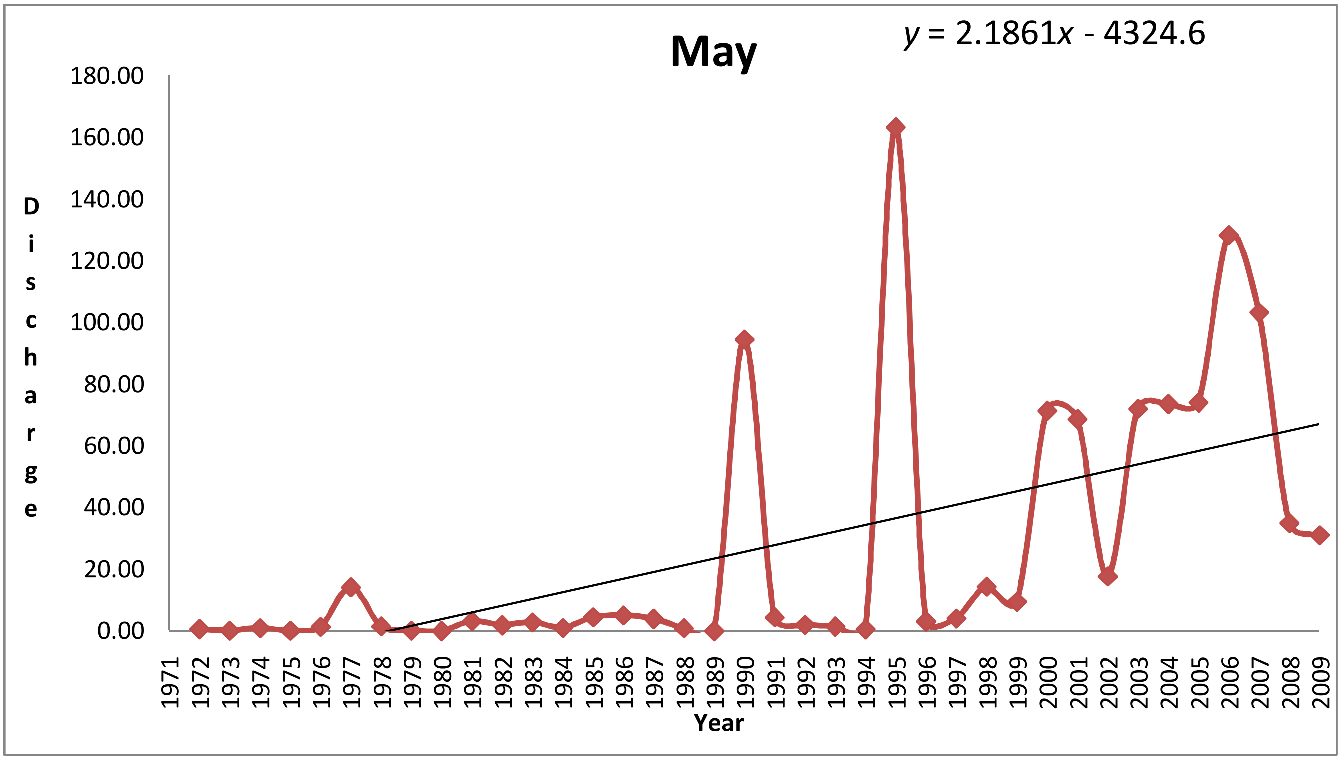
11. MEAN DAILY DISCHARGE OF EACH MONTH (FITTED WITH LINEAR TREND LINE)

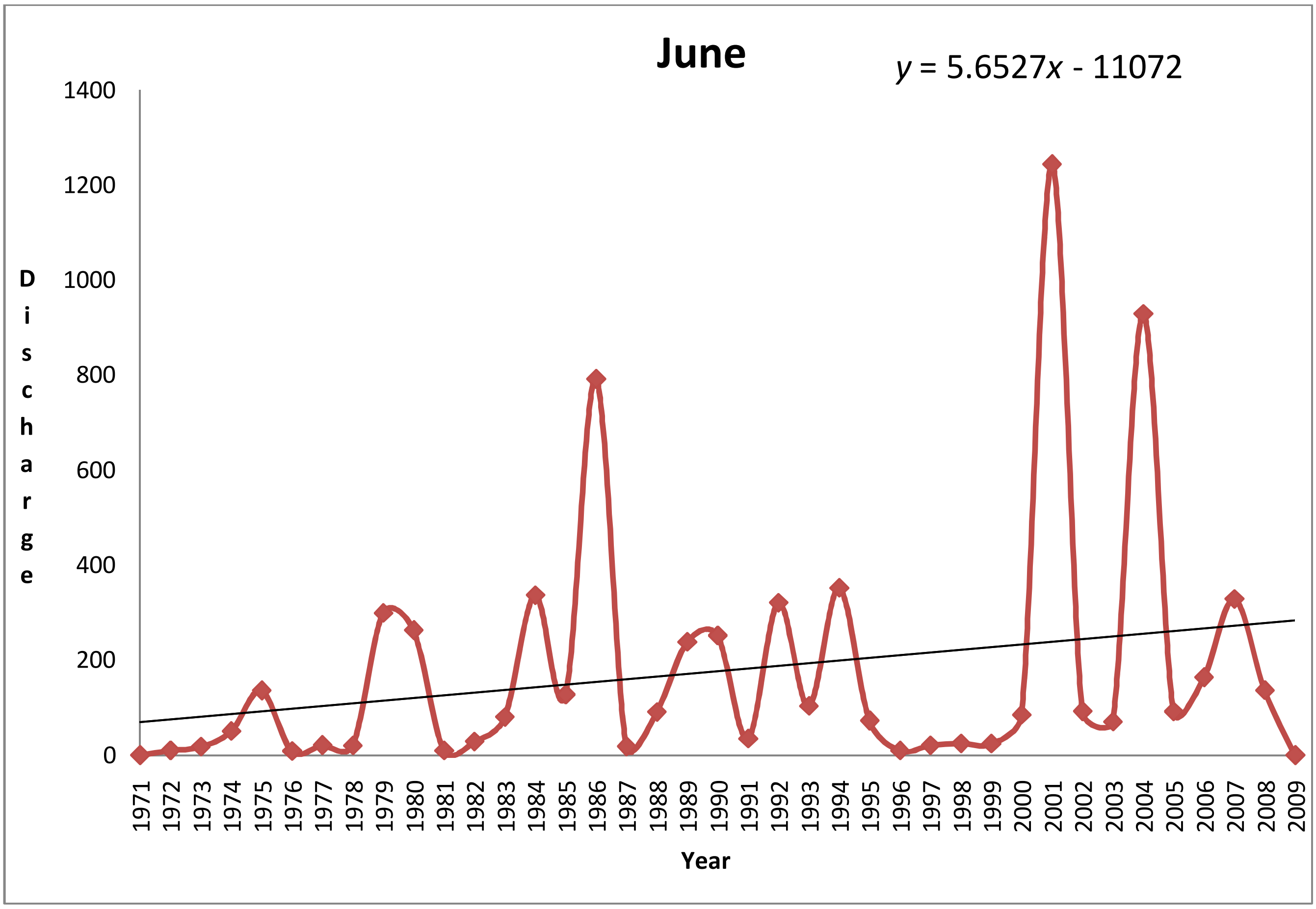


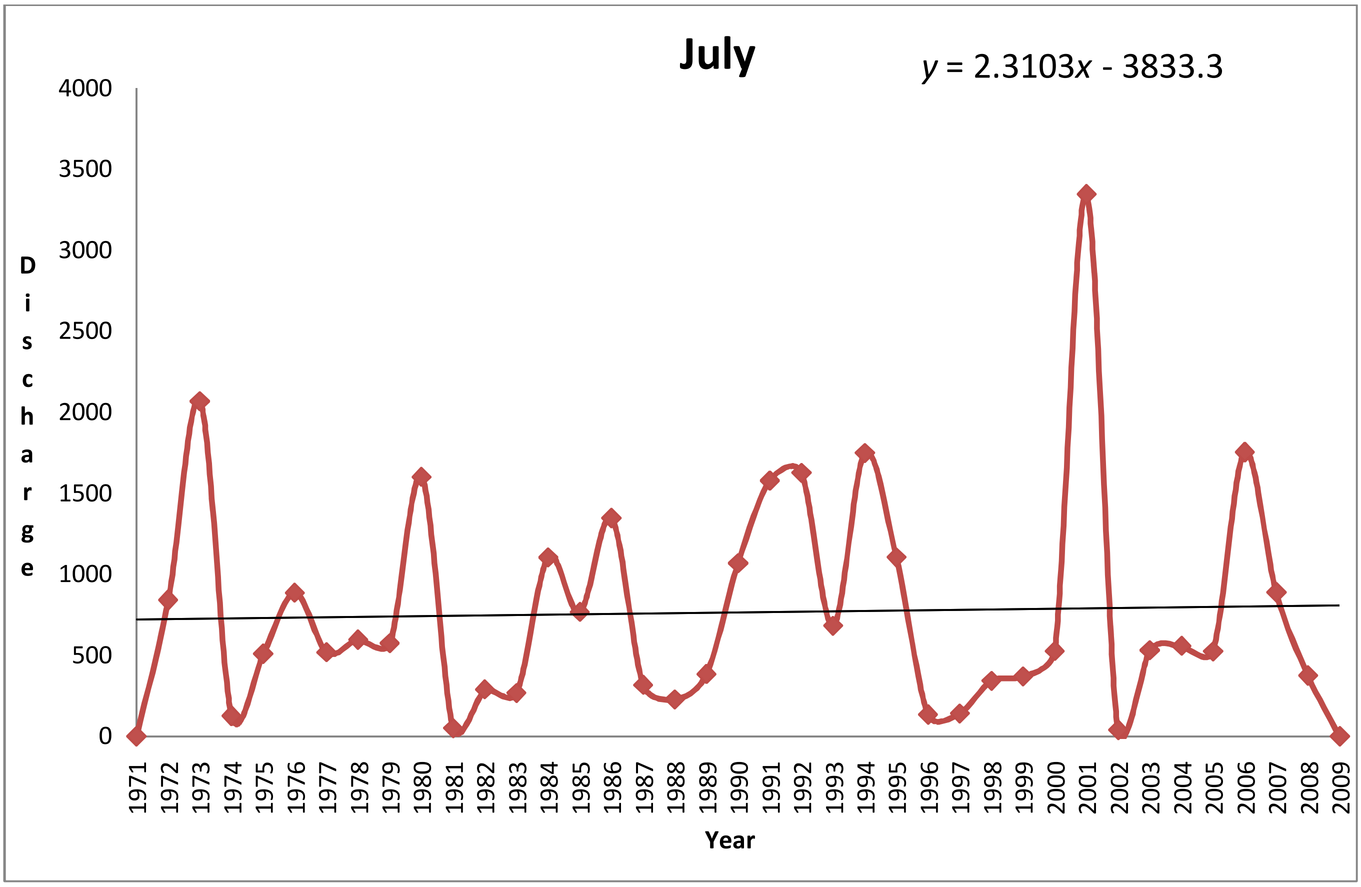


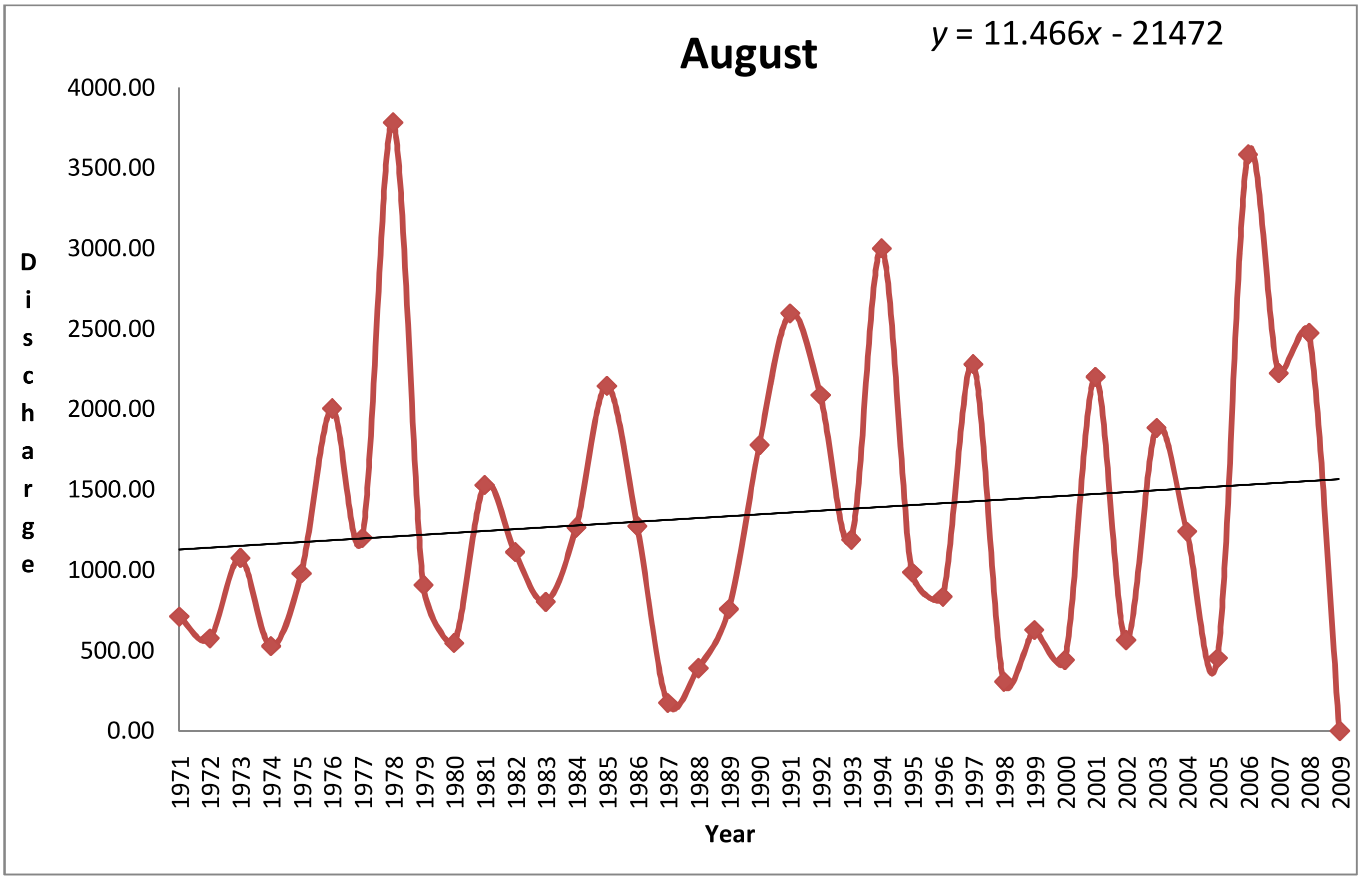

March
y = 0.587x - 1160.
Discharge
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
Year

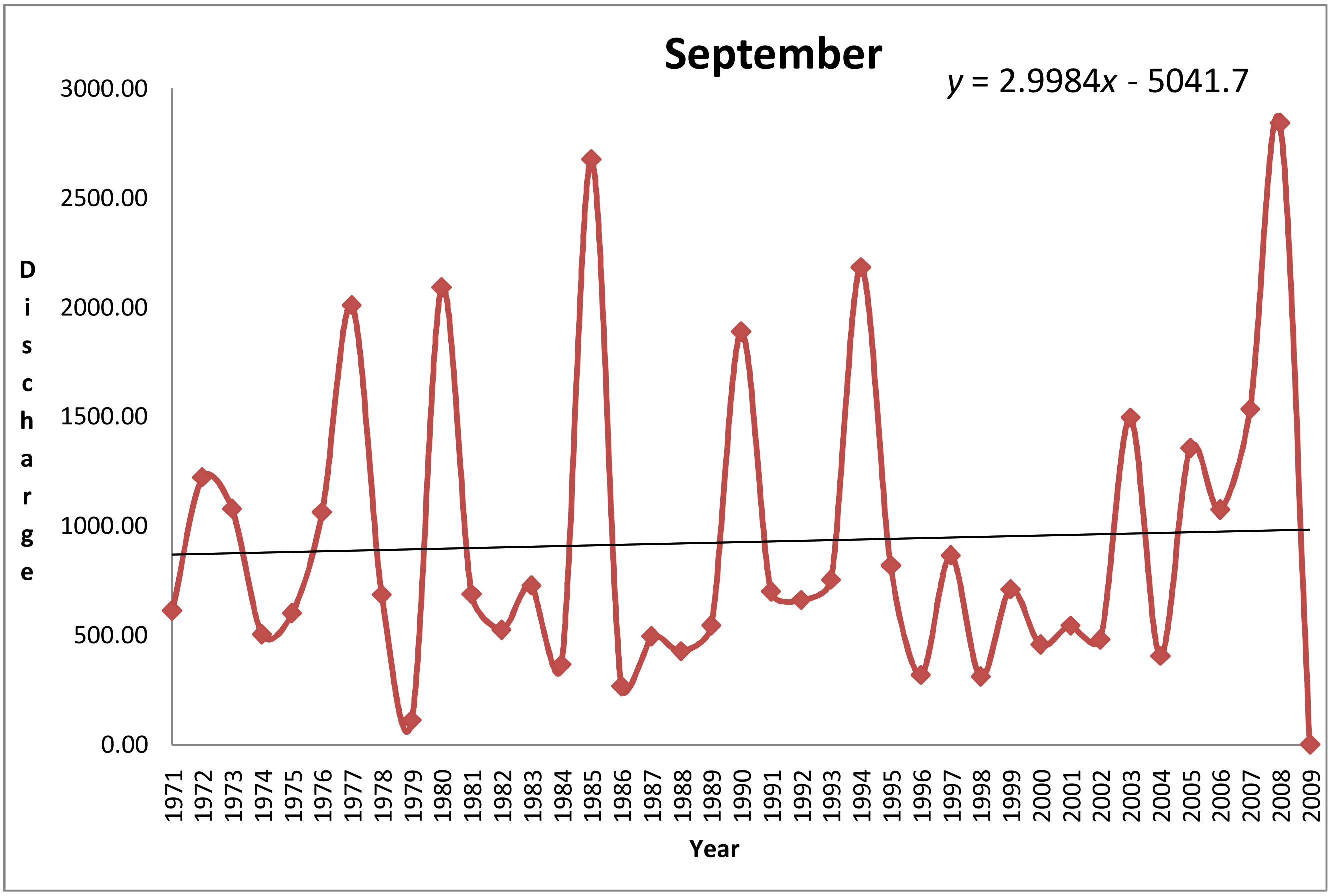

April
y = 0.616x - 1218.4
Discharge
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
Year

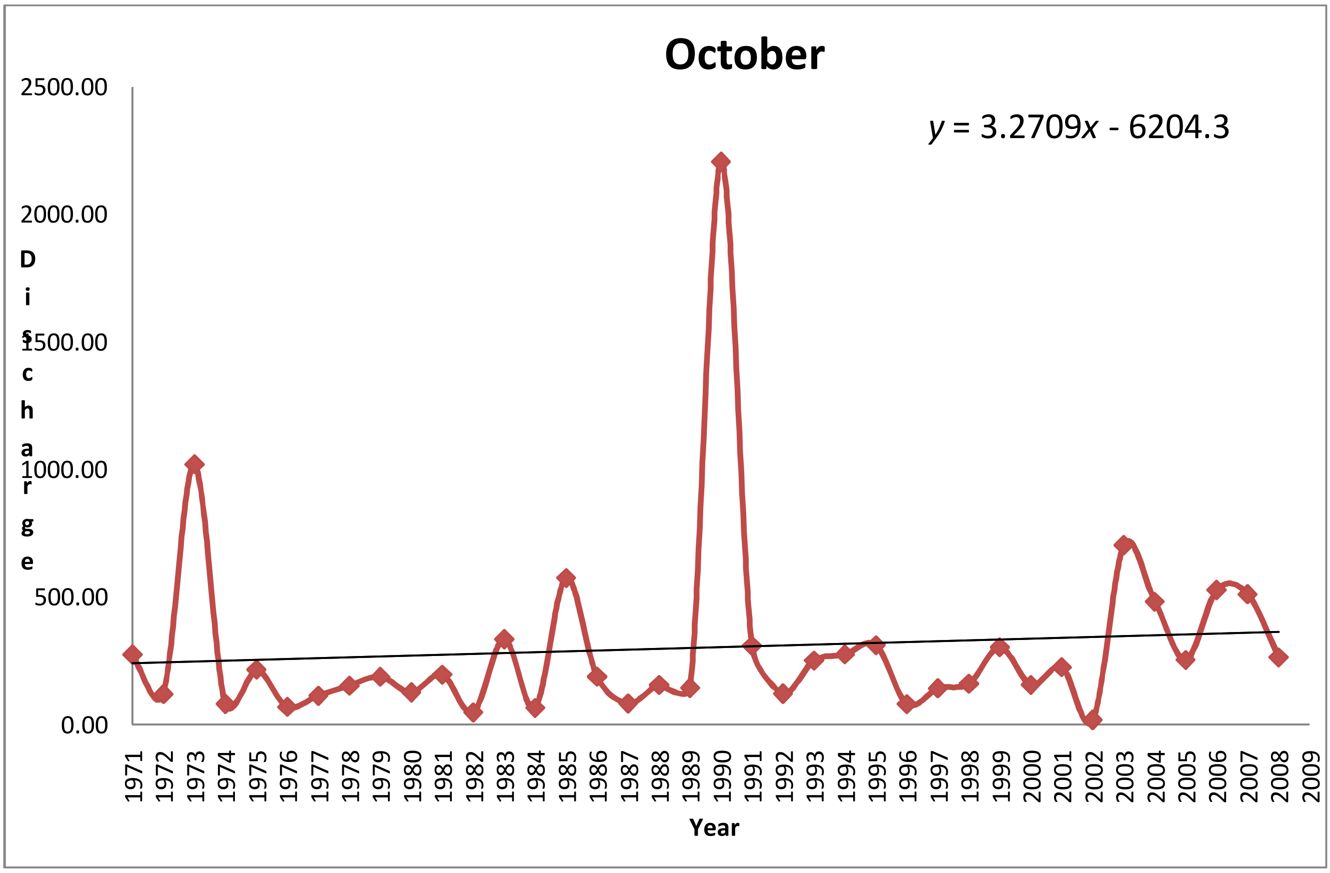

May
y = 2.1861x - 4324.6
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Discharge
1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
Year

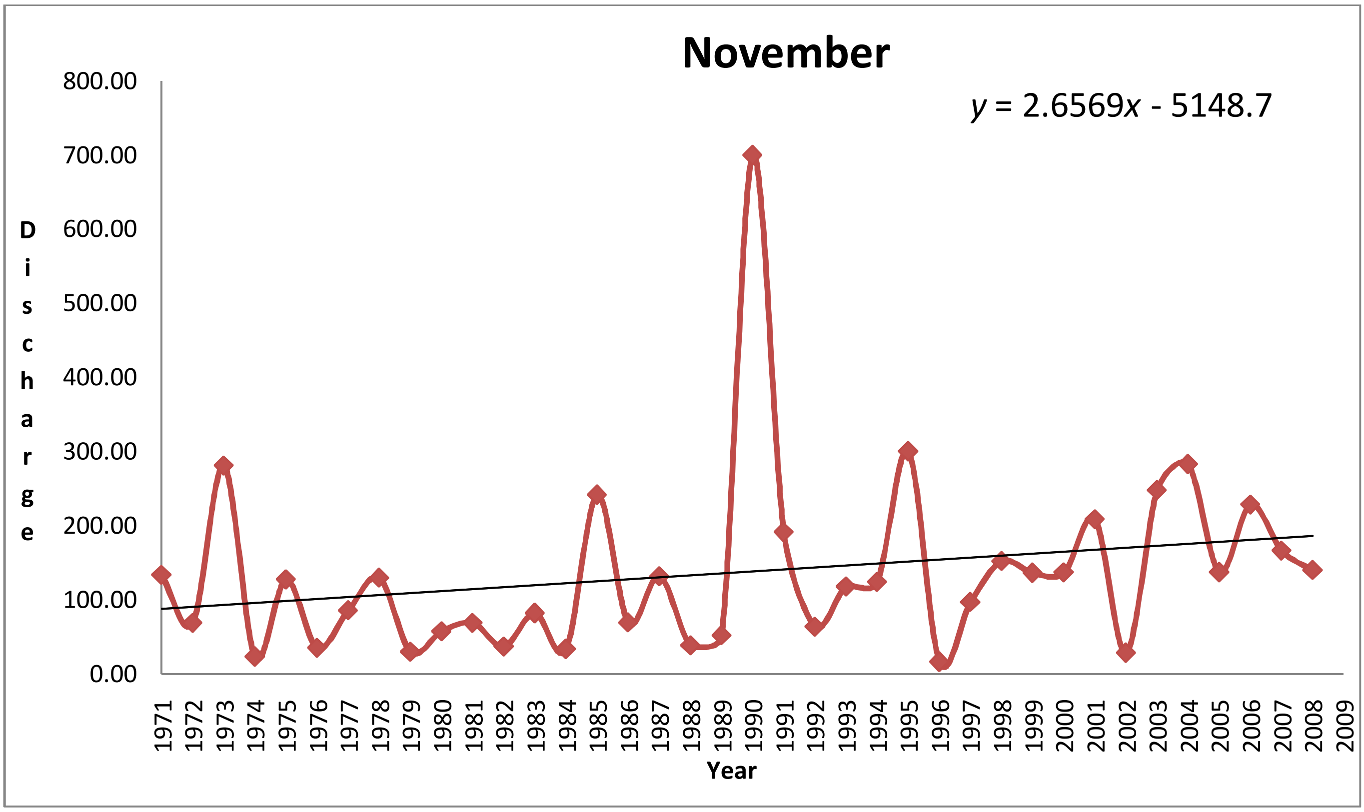

June
y = 5.6527x - 11072
1400
1200
1000
800
600
400
200
0
Discharge
1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
Year

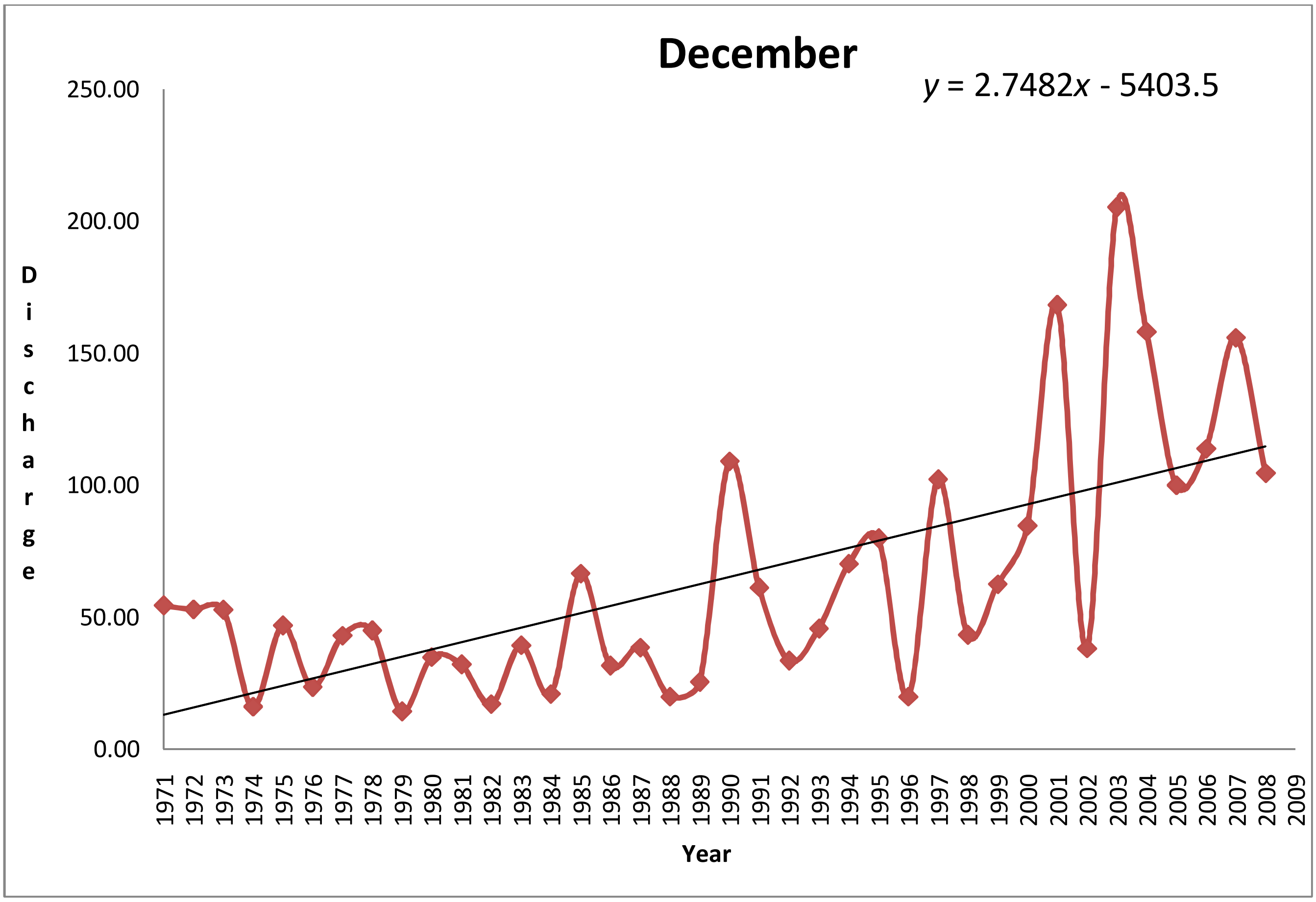

July
y = 2.3103x - 3833.3
Discharge
4000
3500
3000
2500
2000
1500
1000
500
0
1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
Year


August
y = 11.466x - 21472
Discharge
4000.00
3500.00
3000.00
2500.00
2000.00
1500.00
1000.00
500.00
0.00
1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
Year


September
y = 2.9984x - 5041.7
3000.00
2500.00
2000.00
1500.00
1000.00
500.00
0.00
Discharge
1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
Year


October
y = 3.2709x - 6204.3
2500.00
2000.00
1500.00
1000.00
500.00
0.00
Discharge
1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
Year


November
y = 2.6569x - 5148.7
Discharge
800.00
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
Year


December
y = 2.7482x - 5403.5
Discharge
250.00
200.00
150.00
100.00
50.00
0.00
1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
Year

12. RESULTS and DISCUSSIONS

The results obtained through Mann-Kendall analysis have been summarized in Table 12.1 and 12.2.

Table 12.1. Standard Deviation and Skewness of Daily Discharge

	AVG DAILY DISCHARGE	STDEV	SKEWNESS
JUNE	173.87	678.350	9.471
JULY	766.22	1565.639	5.782
AUG	1343.82	1875.107	3.589
SEPT	901.29	1528.573	6.124
OCT	304.89	627.962	9.781
NOV	131.69	177.764	8.047
DEC	63.83	52.684	1.195
JAN	37.15	42.365	1.848
FEB	25.43	36.145	1.776
MAR	20.79	33.615	2.241
APRIL	17.63	31.099	2.662
MAY	26.56	62.754	7.981

12.1. PROBABILITY DISTRIBUTION

The probability is obtained from the NORMSDIST (Z) function. The trend is said to be increasing when Z is positive and level of significance (probability) is greater than 95%. If Z=0 or probability<95 %, trend cannot be inferred. The results are summarized in Table 13.2.

Table 12.2. Probability and Trend at Kantamal station

Month	S	var	Z	normsdist	probability	trend
JANUARY	49	6327	0.6034	0.7269	98.266%	Increasing
FEBRUARY	23	6327	0.2766	0.6089	64.697%	Increasing
MARCH	45	6327	0.5531	0.7099	76.705%	No Trend
APRIL	43	6327	0.5280	0.7012	57.971%	No Trend
MAY	-1	6327	0.0000	0.5000	96.488%	No Trend
JUNE	7	6327	0.0754	0.5301	93.746%	Increasing
JULY	17	6327	0.2011	0.5797	99.643%	Increasing
AUGUST	19	6327	0.2263	0.5895	99.971%	Increasing
SEPTEMBER	23	6327	0.2765	0.6089	99.969%	Increasing
OCTOBER	33	6327	0.4023	0.6563	99.987%	Increasing
NOVEMBER	31	6327	0.3771	0.6470	99.981%	Increasing
DECEMBER	41	6327	0.5028	0.6925	99.995%	Increasing

13. CONCLUSIONS

The objective of the Mann-Kendal Rank Correlation Test is to detect the presence of an increasing or decreasing trend in the whole time series. The Mann-Kendall methods yield consistent test results for most rainfall characteristics and geographic regions. Some of the significant changes are the detection of an increasing trend in the mean annual rainfall from 1971-2009 at a level of significance of 95% in the Tel sub-basin. The mean daily runoff has seen a significant increasing trend. There is an increase in the non-monsoon runoff in the observed discharge station, signifying abundance of fresh water and the importance of better water management practices in the future. For the monsoon months there has been a slight increase in average daily runoff. However the minute increase in runoff in the monsoon months has been summarized as a ‘no trend’ as the level of significance is less than 95% through the Mann-Kendall test. The graphs plotted for each month using a linear trend line show an uptrend in the non-monsoon months and support the analysis done through the Mann-Kendall test.

Though the steady increase of annual rainfall in the non-monsoon months could not be attributed to any single physical mechanism, the increasing trend in the greenhouse gases in the atmosphere, especially CO_2 and CH_4 and changes in land-use patterns were found to have a bearing on the observed increasing trend in the basin.

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